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ANNUAL REPORT OF THE
BOARD OF REGENTS OF
THE SMITHSONIAN
INSTITUTION

SHOWING THE
OPERATIONS, EXPENDITURES, AND
CONDITION OF THE INSTITUTION
FOR THE YEAR ENDING JUNE 30
1932



SMITHSONIAN INSTITUTION
WASHINGTON

ANNUAL REPORT OF THE
BOARD OF REGENTS OF
THE SMITHSONIAN
INSTITUTION

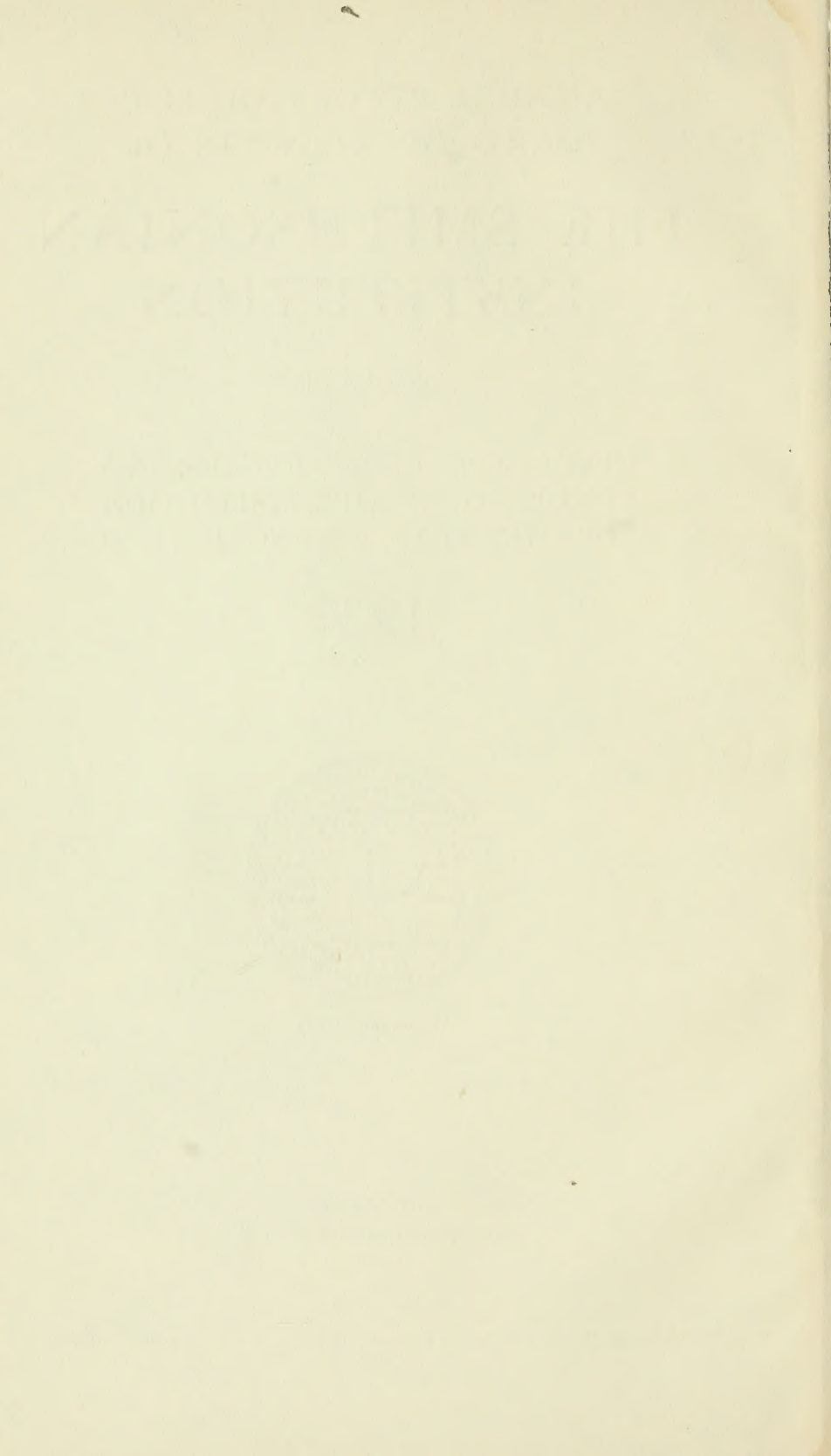
SHOWING THE
OPERATIONS, EXPENDITURES, AND
CONDITION OF THE INSTITUTION
FOR THE YEAR ENDING JUNE 30

1932



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UNITED STATES
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WASHINGTON : 1933



LETTER

FROM THE

SECRETARY OF THE SMITHSONIAN INSTITUTION

SUBMITTING

THE ANNUAL REPORT OF THE BOARD OF REGENTS OF THE
INSTITUTION FOR THE YEAR ENDED JUNE 30, 1932

SMITHSONIAN INSTITUTION,

Washington, November 30, 1932.

To the Congress of the United States:

In accordance with section 5593 of the Revised Statutes of the United States, I have the honor, in behalf of the Board of Regents, to submit to Congress the annual report of the operations, expenditures, and condition of the Smithsonian Institution for the year ended June 30, 1932. I have the honor to be,

Very respectfully, your obedient servant,

C. G. ABBOT, *Secretary.*

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¹ In part govermentally supported.

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ANNUAL REPORT OF THE BOARD OF REGENTS OF THE SMITHSONIAN
INSTITUTION FOR THE YEAR ENDING JUNE 30, 1932

SUBJECTS

1. Annual report of the secretary, giving an account of the operations and conditions of the Institution for the year ending June 30, 1932, with statistics of exchanges, etc.
2. Report of the executive committee of the Board of Regents, exhibiting the financial affairs of the Institution, including a statement of the Smithsonian fund, and receipts and expenditures for the year ending June 30, 1932.
3. Proceedings of the Board of Regents for the fiscal year ending June 30, 1932.
4. General appendix, comprising a selection of miscellaneous memoirs of interest to collaborators and correspondents of the Institution, teachers, and others engaged in the promotion of knowledge. These memoirs relate chiefly to the calendar year 1932.

THE SMITHSONIAN INSTITUTION

June 30, 1932

Presiding officer ex officio.—HERBERT HOOVER, President of the United States.
Chancellor.—CHARLES EVANS HUGHES, Chief Justice of the United States.

Members of the Institution:

HERBERT HOOVER, President of the United States.
CHARLES CURTIS, Vice President of the United States.
CHARLES EVANS HUGHES, Chief Justice of the United States.
HENRY L. STIMSON, Secretary of State.
OGDEN L. MILLS, Secretary of the Treasury.
PATRICK J. HURLEY, Secretary of War.
WILLIAM D. MITCHELL, Attorney General.
WALTER F. BROWN, Postmaster General.
CHARLES FRANCIS ADAMS, Secretary of the Navy.
RAY LYMAN WILBUR, Secretary of the Interior.
ARTHUR M. HYDE, Secretary of Agriculture.
ROY D. CHAPIN, Secretary of Commerce.
WILLIAM N. DOAK, Secretary of Labor.

Regents of the Institution:

CHARLES EVANS HUGHES, Chief Justice of the United States, Chancellor.
CHARLES CURTIS, Vice President of the United States.
REED SMOOT, Member of the Senate.
JOSEPH T. ROBINSON, Member of the Senate.
CLAUDE A. SWANSON, Member of the Senate.
ALBERT JOHNSON, Member of the House of Representatives.
T. ALAN GOLDSBOROUGH, Member of the House of Representatives.
EDWARD H. CRUMP, Member of the House of Representatives.
IRWIN B. LAUGHLIN, citizen of Pennsylvania.
FREDERIC A. DELANO, citizen of Washington, D. C.
JOHN C. MERRIAM, citizen of Washington, D. C.
R. WALTON MOORE, citizen of Virginia.
ROBERT W. BINGHAM, citizen of Kentucky.
AUGUSTUS P. LORING, citizen of Massachusetts.

Executive committee.—FREDERIC A. DELANO, R. WALTON MOORE, JOHN C. MERRIAM.

Secretary.—CHARLES G. ABBOT.

Assistant Secretary.—ALEXANDER WETMORE.

Chief Clerk and administrative assistant to the Secretary.—HARRY W. DORSEY.
Treasurer and disbursing agent.—NICHOLAS W. DORSEY.

Editor.—WEBSTER P. TRUE.

Librarian.—WILLIAM L. CORBIN.

Appointment clerk.—JAMES G. TRAYLOR.

Property clerk.—JAMES H. HILL.

NATIONAL MUSEUM

Keeper ex officio.—CHARLES G. ABBOT.

Assistant Secretary (in charge).—ALEXANDER WETMORE.

Associate director.—JOHN E. GRAF.

Administrative assistant to the Secretary.—WILLIAM DE C. RAVENEL.

Head curators.—WALTER HOUGH, LEONHARD STEJNEGER, RAY S. BASSLER.

Curators.—PAUL BARTSCH, RAY S. BASSLER, THEODORE T. BELOTE, AUSTIN H. CLARK, FREDERICK V. COVILLE, WILLIAM F. FOSHAG, HERBERT FRIEDMANN, CHESTER G. GILBERT, CHARLES W. GILMORE, WALTER HOUGH, LELAND O. HOWARD, ALEŠ HRDLÍČKA, NEIL M. JUDD, HERBERT W. KRIEGER, FREDERICK L. LEWTON, GERRIT S. MILLER, JR., CARL W. MITMAN, CHARLES E. RESSER, WALDO L. SCHMITT, LEONHARD STEJNEGER, RUEL P. TOLMAN.

Associate curators.—JOHN M. ALDRICH, ELLSWORTH P. KILLIP, WILLIAM R. MAXON, JOSEPH H. RILEY, DAVID WHITE.

Chief of correspondence and documents.—HERBERT S. BRYANT.

Disbursing agent.—NICHOLAS W. DORSEY.

Superintendent of buildings and labor.—JAMES S. GOLDSMITH.

Editor.—PAUL H. OEHSE.

Assistant Librarian.—LEILA G. FORBES.

Photographer.—ARTHUR J. OLMSTED.

Property clerk.—WILLIAM A. KNOWLES.

Engineer.—CLAYTON R. DENMARK.

NATIONAL GALLERY OF ART

Director.—WILLIAM H. HOLMES.

FREER GALLERY OF ART

Curator.—JOHN ELLERTON LODGE.

Associate curator.—CARL WHITING BISHOP.

Assistant curator.—GRACE DUNHAM GUEST.

Associate.—KATHARINE NASH RHOADES.

Assistant.—ARCHIBALD G. WENLEY.

Superintendent.—JOHN BUNDY.

BUREAU OF AMERICAN ETHNOLOGY

Chief.—MATTHEW W. STIRLING.

Ethnologists.—JOHN P. HARRINGTON, JOHN N. B. HEWITT, TRUMAN MICHELSON,

JOHN R. SWANTON, WILLIAM D. STRONG.

Archeologist.—FRANK H. H. ROBERTS, JR.

Associate Anthropologist.—WINSLOW M. WALKER.

Editor.—STANLEY SEARLES.

Librarian.—ELLA LEARY.

Illustrator.—DE LANCEY GILL.

INTERNATIONAL EXCHANGES

Secretary (in charge).—CHARLES G. ABBOT.

Chief clerk.—COATES W. SHOEMAKER.

NATIONAL ZOOLOGICAL PARK

Director.—WILLIAM M. MANN.

Assistant director.—ERNEST P. WALKER.

ASTROPHYSICAL OBSERVATORY

Director.—CHARLES G. ABBOT.

Assistant director.—LOYAL B. ALDRICH.

Research assistant.—FREDERICK E. FOWLE, JR.

Associate research assistant.—WILLIAM H. HOOVER.

DIVISION OF RADIATION AND ORGANISMS

Chief.—FREDERICK S. BRACKETT.

Research associate.—EARL S. JOHNSTON.

Associate research assistant.—E. D. MCALISTER.

Research assistant.—LELAND B. CLARK.

REGIONAL BUREAU FOR THE UNITED STATES, INTERNATIONAL
CATALOGUE OF SCIENTIFIC LITERATURE

Assistant in charge.—LEONARD C. GUNNELL.

REPORT OF THE SECRETARY OF THE SMITHSONIAN INSTITUTION

C. G. ABBOT

FOR THE YEAR ENDING JUNE 30, 1932

To the Board of Regents of the Smithsonian Institution.

GENTLEMEN: I have the honor to submit herewith my report showing the activities and condition of the Smithsonian Institution and the Government bureaus under its administrative charge during the fiscal year ended June 30, 1932. The first 14 pages contain a summary account of the affairs of the Institution. Appendixes 1 to 11 give more detailed reports of the operations of the United States National Museum, the National Gallery of Art, the Freer Gallery of Art, the Bureau of American Ethnology, the International Exchanges, the National Zoological Park, the Astrophysical Observatory, the Division of Radiation and Organisms, the United States Regional Bureau of the International Catalogue of Scientific Literature, the Smithsonian library, and of the publications issued under the direction of the Institution.

THE SMITHSONIAN INSTITUTION

OUTSTANDING EVENTS OF THE YEAR

Preliminary plans have been completed for the wings authorized in 1930 to be added to the Natural History Building of the National Museum; appropriations have not yet been made, however, to begin construction. An unrestricted bequest of \$100,000 was received for the endowment funds of the Institution from the late Dwight W. Morrow. Two \$2,500 Research Corporation awards were made through the Institution to Doctors Douglass and Antevs. Two notable public lectures were given at the Institution, the first Arthur Lecture by Dr. Henry Norris Russell and the sixth Hamilton Lecture by Dr. Albert Charles Seward. Volume 12, the last volume of the Smithsonian Scientific Series, was sent to the printer near the close of the year. The fifth revised edition of the Smithsonian Meteorological Tables and the fourth reprint of the Smithsonian

Mathematical Tables—Hyperbolic Functions—were issued. A considerable number of scientific expeditions were in the field from the Institution, the National Museum, and the Bureau of American Ethnology; these expeditions brought back valuable new information and collections bearing on the Institution's researches. The Director of the National Zoological Park headed an expedition to British Guiana, returning with 317 live animals for the park. Volume V of the *Annals of the Astrophysical Observatory* appeared, presenting the results of its researches on the sun for the past 10 years. New instruments for the solar work were devised, and investigations were made of periodicities in solar and terrestrial phenomena. The Division of Radiation and Organisms, pursuing its pioneering experiments in biophysics, measured the carbon-dioxide assimilation of wheat for different light intensities, made experiments on the lethal effects of the ultra-violet rays upon algae, and a study of the effects of different wave-length distributions of light on the growth of plants. The reduction in the Institution's income, both private and governmental, has occasioned strict economy in all lines and the curtailment of some activities. Its funds for publication have been cut nearly to one-half of last year's amount, with the result that valuable manuscripts have had to be refused or held up for a year and others have been cut to half their normal size, as has been done, for instance, with this report.

THE ESTABLISHMENT

The Smithsonian Institution was created by act of Congress in 1846, according to the terms of the will of James Smithson, of England, who in 1826 bequeathed his property to the United States of America "to found at Washington, under the name of the Smithsonian Institution, an establishment for the increase and diffusion of knowledge among men." In receiving the property and accepting the trust, Congress determined that the Federal Government was without authority to administer the trust directly and, therefore, constituted an "establishment" whose statutory members are "the President, the Vice President, the Chief Justice, and the heads of the executive departments."

THE BOARD OF REGENTS

The affairs of the Institution are administered by a Board of Regents whose membership consists of "the Vice President, the Chief Justice, three Members of the Senate, and three Members of the House of Representatives, together with six other persons other than Members of Congress, two of whom shall be resident in the city

of Washington and the other four shall be inhabitants of some State, but no two of them of the same State." One of the Regents is elected chancellor of the board. In the past the selection has fallen upon the Vice President or the Chief Justice, and a suitable person is chosen by the Regents as Secretary of the Institution, who is also secretary of the Board of Regents, and the executive officer directly in charge of the Institution's activities.

A number of changes in the personnel of the board occurred during the year. The terms as Regents of three congressional members expired—Representatives R. Walton Moore, Robert Luce, and Albert Johnson. Six vacancies on the board were filled by the appointment or reappointment of three Members of Congress—Representatives Albert Johnson, T. Alan Goldsborough, and A. J. Montague—and three citizen Regents—R. Walton Moore, Virginia; Robert W. Bingham, Kentucky; and Augustus P. Loring, Massachusetts. A. J. Montague having resigned, E. H. Crump was appointed to succeed him.

The roll of Regents at the close of the year was as follows: Charles Evans Hughes, Chief Justice of the United States, chancellor; Charles Curtis, Vice President of the United States; Members from the Senate—Reed Smoot, Joseph T. Robinson, Claude A. Swanson; Members from the House of Representatives—Albert Johnson, T. Alan Goldsborough, E. H. Crump; citizen members—Frederic A. Delano, Washington, D. C.; Irwin B. Laughlin, Pennsylvania; John C. Merriam, Washington, D. C.; R. Walton Moore, Virginia; Robert W. Bingham, Kentucky; Augustus P. Loring, Massachusetts.

FINANCES

PRIVATE FUNDS

The permanent investments of the Institution consist of the following:

Total endowment for general or specific purposes (exclusive of Freer funds)-----	\$1,775,804.36
<hr/>	
Itemized as follows:	
Deposited in the Treasury of the United States, as provided by law-----	1,000,000.00
Deposited in the consolidated fund—	
Miscellaneous securities, etc., either purchased or acquired by gift; cost or value at date acquired-----	712,156.86
Springer, Frank, fund for researches, etc. (bonds)-----	13,835.00
Younger, Helen Walcott, fund (real-estate notes and stock held in trust)-----	49,812.50
Total-----	1,775,804.36
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The above-mentioned funds of the Institution are described as follows:

Fund	United States Treasury	Consolidated fund	Separate funds	Total
Arthur, James, fund.....		\$50,699.31		\$50,699.31
Bacon, Virginia Purdy, fund.....		63,512.52		63,512.52
Baird, Lucy H., fund.....		9,959.05		9,959.05
Barstow, Frederic D., fund.....		964.27		964.27
Canfield Collection fund.....		48,488.51		48,488.51
Casey, Thomas L., fund.....		9,797.14		9,797.14
Chamberlain fund.....		35,698.68		35,698.68
Hodgkins (specific) fund.....	\$100,000.00			100,000.00
Hughes, Bruce, fund.....		19,205.63		19,205.63
Myer, Catherine W., fund.....		22,907.94		22,907.94
Pell, Cornelia Livingston, fund.....		3,060.69		3,060.69
Poore, Lucy T. and George W., fund.....	26,670.00	36,172.17		62,842.17
Reid, Addison T., fund.....	11,000.00	14,478.94		25,478.94
Roebeling Collection fund.....		152,987.77		152,987.77
Rollins, Miriam and William, fund.....		53,787.00		53,787.00
Smithsonian unrestricted funds:				
Avery fund.....	14,000.00	47,207.09		61,207.09
Endowment fund.....		81,374.67		81,374.67
Habel fund.....	500.00			500.00
Hachenberg fund.....		5,100.49		5,100.49
Hamilton fund.....	2,500.00	511.70		3,011.70
Henry fund.....		1,533.17		1,533.17
Hodgkins general fund.....	116,000.00	38,018.94		154,018.94
Parent fund.....	727,640.00	1,547.50		729,187.50
Rhees fund.....	500.00	599.63		1,189.63
Sanford fund.....	1,100.00	1,128.49		2,228.49
Springer fund.....			\$13,835.00	13,835.00
Walcott, Charles D. and Mary Vaux, fund.....		12,450.72		12,450.72
Younger, Helen Walcott, fund.....			49,812.50	49,812.50
Zerbee, Frances Brincklé, fund.....		964.84		964.84
Total.....	1,000,000.00	712,156.86	63,647.50	1,775,804.36

Freer Gallery of Art.—The invested funds of the Freer bequest are classified as follows:

Court and grounds fund.....	\$580,016.22
Court and grounds maintenance fund.....	145,171.79
Curator fund.....	589,763.31
Residuary legacy.....	3,858,208.44
Total.....	5,173,159.76

Recapitulation of endowment funds, June 30, 1932

Endowment for general purposes.....	\$1,039,351.68
Endowment for specific purposes other than Freer endowment....	736,452.68
Total endowment other than Freer endowment.....	1,775,804.36
Freer endowment.....	5,173,159.76

STATEMENT OF INCOME

PARENT INSTITUTION

Expendable income for fiscal year:

Cash income from all sources for general work of the Institution.....	\$74,883.41
Cash income from investments and other sources for specific objects.....	27,393.29
Cash gifts expendable for specific objects.....	33,761.71
Total.....	136,038.41

Increase of endowment:

Endowment for general work of the Institution-----	\$108,020.39
Endowment for specific uses-----	7,430.71
Total-----	115,451.10

FREER GALLERY OF ART

Expendable income for fiscal year: Cash income for general work of the gallery-----	281,476.85
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The practice of depositing on time in local trust companies and banks such revenues as may be spared temporarily has been continued during the past year, and interest on these deposits has amounted to \$5,364.02.

The Institution gratefully acknowledges gifts or bequests from the following:

Dr. W. L. Abbot, for archeological investigations in Cuba and the Bahama Islands.

Mrs. Laura Welsh Casey, further contributions to the Thomas Lincoln Casey fund for investigations in Coleoptera.

The estate of Dwight W. Morrow, for general endowment fund of the Institution.

Mr. Childs Frick, further contributions for researches in vertebrate paleontology.

Research Corporation, for further contributions for researches in radiation.

Rockefeller Foundation, for further contributions for researches in radiation.

Mr. John A. Roebling, for further contributions for researches in radiation.

The estate of William H. Rollins, for investigations in physics and chemistry.

Mrs. Mary Vaux Walcott, for archeological investigations in Alaska.

From an anonymous friend, for further investigations in Old World archeology.

PUBLIC FUNDS

The following appropriations were made by Congress for the Government bureaus under the administrative charge of the Smithsonian Institution for the fiscal year 1932:

Salaries and expenses-----	\$38,644.00
Gellatly art collection-----	20,000.00
International Exchanges-----	54,060.00
American Ethnology-----	72,640.00
International Catalogue of Scientific Literature-----	8,150.00
Astrophysical Observatory-----	37,620.00
National Museum:	
Maintenance and operation ¹ -----	\$154,580.00
Preservation of collections ² -----	620,510.00
	775,090.00
National Gallery of Art-----	45,220.00
National Zoological Park-----	255,540.00

¹ Former appropriations "Furniture and fixtures," "Heating and lighting," and "Building repairs" provided for under this appropriation.

² Former appropriations "Books" and "Postage" merged with "Preservation of collections" and provided for under this appropriation.

National Zoological Park, plans for building for small mammals--	\$4,500.00
Printing and binding-----	104,000.00
Total-----	1,415,464.00

MATTERS OF GENERAL INTEREST

DWIGHT W. MORROW BEQUEST

Under the terms of the will of Dwight W. Morrow, former ambassador to Mexico and later United States Senator from New Jersey, who died October 5, 1931, the Institution received a bequest of \$100,000. The legacy reads as follows:

To the Smithsonian Institution, city of Washington, District of Columbia, one hundred thousand dollars (\$100,000), to be part of its endowment funds.

Mr. Morrow, who for several years was a member of the Board of Regents of the Smithsonian Institution, had taken an active interest in its affairs. His generous bequest is a substantial indication of that interest; it will be particularly valuable to the Institution because it is unhampered by conditions in the application of its income, making it possible to assign the additional funds thus provided to the researches most in need of assistance.

RESEARCH CORPORATION AWARDS TO DOCTORS DOUGLASS AND ANTEVS

In recognition of their outstanding scientific researches the fourth and fifth Research Corporation awards of \$2,500 each were made through the Smithsonian Institution to Dr. Andrew Ellicott Douglass and Dr. Ernst Antevs on December 18, 1931. The presentation was made in the auditorium of the National Museum, the exercises opening with an account of the Research Corporation and its awards by the Secretary of the Institution, and informally by Mr. Elon Hooker, a director of the corporation. This was followed by the formal presentation by Chief Justice Charles Evans Hughes, chancellor of the Institution, and the recipients then delivered addresses on their researches. An account of the ceremony, together with the full text of the addresses of Doctors Douglass and Antevs, will be found in the general appendix to the Smithsonian Report for 1931.

LECTURES

Arthur Lecture.—The first lecture under the bequest of James Arthur, received by the Institution in 1931, was given by Dr. Henry Norris Russell, professor of astronomy at Princeton University, who lectured on The Composition of the Sun, in the auditorium of the National Museum on the evening of January 27, 1932. The lecture is being published in the Smithsonian Report for 1931.

Hamilton Lecture.—The sixth Hamilton Lecture was given on the evening of March 30, 1932, also in the auditorium of the Museum,

by Dr. Albert Charles Seward, master of Downing College and professor of botany, Cambridge University. Doctor Seward's subject was Plant Records of the Rocks; the lecture will appear in the Smithsonian Report for 1932.

Lecture on anthropological work in Alaska.—On February 24, 1932, Dr. Aleš Hrdlička, curator of physical anthropology in the National Museum, lectured on Anthropological Exploration in Alaska, under the auspices of the Institution.

SMITHSONIAN SCIENTIFIC SERIES

The Smithsonian Scientific Series is a set of 12 volumes, written in popular style and profusely illustrated, on the various branches of science included in the scope of the Institution's work. The books were written by members of the staff and collaborators of the Institution, and they are published and sold by a New York corporation, the Smithsonian Institution Series, Inc. The Institution receives a definite royalty on all sales. Three-fourths of all receipts are added to the permanent endowment, the remainder used as income to promote the Smithsonian program of research and publication.

Eleven volumes of the series have thus far been issued and the twelfth and last was in press at the close of the fiscal year. The titles and authors are as follows:

1. The Smithsonian Institution, by Webster Prentiss True.
2. The Sun and the Welfare of Man, by Charles Greeley Abbot.
3. Minerals from Earth and Sky. Part I, The Story of Meteorites, by George P. Merrill; Part II, Gems and Gem Minerals, by William F. Foshag.
4. The North American Indians. An account of the American Indians north of Mexico, compiled from the original sources, by Rose A. Palmer.
5. Insects: Their Ways and Means of Living, by R. E. Snodgrass.
6. Wild Animals in and out of the Zoo, by William M. Mann.
7. Man from the Farthest Past, by C. W. Bishop, C. G. Abbot, and A. Hrdlička.
8. Cold-Blooded Vertebrates, by C. W. Gilmore, D. M. Cochran, and S. F. Hildebrand.
9. Warm-Blooded Vertebrates. Part I, Birds, by Alexander Wetmore; Part II, Mammals, by Gerrit S. Miller, jr., and James W. Gidley.
10. Shelled Invertebrates of the Past and Present, with Chapters on Geological History, by Ray S. Bassler, Charles E. Resser, Waldo L. Schmitt, and Paul Bartsch.
11. Old and New Plant Lore, by Agnes Chase, A. S. Hitchcock, Earl S. Johnston, J. H. Kempton, Ellsworth P. Killip, Daniel T. MacDougal, Albert Mann, and William R. Maxon.
12. Great Inventions, by Charles Greeley Abbot.

COOPERATIVE ETHNOLOGICAL AND ARCHEOLOGICAL INVESTIGATIONS

In 1928 Congress appropriated \$20,000 for cooperative ethnological and archeological investigations in this country, the allotments to be made on approval of the Secretary of the Institution in amounts

equal to those raised by the organizations proposing the investigations. The fund was nearly exhausted in 1931, but it was possible to make two small allotments this year, bringing to a close this cooperative project.

Allotments from the fund for cooperative ethnological and archeological investigations during the year ended June 30, 1932

1932

- May 12. University of Denver, to excavate two dry caves in southern Colorado, one near La Veta and the other in the Apishapa Valley district; and if time and money permit, to make a reconnaissance of archeological remains in and around the San Dunes National Monument, \$300.
- June 23. Mississippi, Department of Archives and History, to conduct a survey of Choctaw and Chickasaw Indian village sites and excavate prominent mounds in Mississippi, \$259.

EXPLORATIONS AND FIELD WORK

The Institution and its branches sent out or participated in 25 expeditions in the furtherance of its researches in anthropology, biology, geology, and astrophysics. These expeditions visited 13 States of the United States, several countries of Europe, Canada, Alaska, Mexico, Hispaniola, Jamaica, British Guiana, and Southwest Africa. As illustrative of the aims of these expeditions, I may mention Dr. W. F. Foshag's trip to various mining localities in Mexico for the purpose of collecting certain rare minerals and series of specimens illustrating occurrences and ore formation for the National Museum; Dr. Alexander Wetmore's expedition to Hispaniola to obtain needed information on the bird life of that region; and a continuation of Dr. Aleš Hrdlička's anthropological work in Alaska, in the course of which he obtained anthropometric measurements on the living natives and, through excavation, collections of old skeletal and archeological material. The results of these and of the other expeditions of the year are described and illustrated in *Explorations and Field Work of the Smithsonian Institution in 1931*, Smithsonian publication No. 3134.

PUBLICATIONS

The consolidation of the three separate editorial offices of the Institution into one central office under the general direction of the editor of the *Smithsonian*, announced in last year's report, has proved to be a very satisfactory arrangement. The most important results have been more accuracy and greater uniformity of style in the several series issued under the Institution and a shortening of the average time from manuscript to finished book; furthermore, a central contact point is provided between the printer and the edi-

torial staff, and all of the financial and other records are kept in one office, where the status of every publication and allotment is available at any time. One hundred and twenty-one volumes and pamphlets were issued during the year, 50 by the Institution proper, 63 by the National Museum, 7 by the Bureau of American Ethnology, and 1 by the Astrophysical Observatory. Detailed information regarding these publications will be found in the report of the editor, Appendix 11. The total number of publications distributed was 223,045.

LIBRARY

The Smithsonian library, made up of 10 divisional libraries and 35 sectional libraries, now contains more than 800,000 volumes, pamphlets, and charts. Accessions during the year totaled 6,807 volumes and 4,648 pamphlets and charts, most of which were received in exchange. Among the outstanding gifts were a set in 45 volumes of the "Phra Tripitaka" from His Majesty the King of Siam and a copy of "Cristoforo Colombo—Documenti & prove della sua appartenenza a Genova," presented by His Excellency Dino Grandi. Considerable progress was made in recataloguing the botanical collection of the National Museum library, and the reclassifying and recataloguing of the Freer Gallery of Art library was almost completed. Arrangements were made for assembling a dictionary index to all of the publications of the Institution and its branches.

GOVERNMENTALLY SUPPORTED BRANCHES¹

National Museum.—The total appropriations for the past year were \$835,090, an increase of \$4,696 over those for the previous year. Plans were completed for the wings to be added to the Natural History Building, authorized in 1930; but owing to the need for national economy, the estimate of \$1,200,000 to begin construction could not be included in the Budget. Additions to the collections numbered 157,870 specimens, and as usual a large number of specimens were examined and reported upon, exchanged with other institutions, and given to schools. Important accessions in anthropology included collections of artifacts from prehistoric sites in Europe; series of old native implements from Kodiak Island, Alaska; costumes and implements used by the natives of Panama; and native pottery and textiles from Africa. Collections of general biological material were received from Southwest Africa and from Siam. Important series of plants came from the Brazilian-Venezuelan frontier and from Peru. In geology, a large number of interesting minerals were

¹ For further details regarding the work of these branches, see the appendixes at the end of this report.

accessioned, including a gold nugget weighing 81 ounces troy; also important collections of fossils, particularly of mammals. The outstanding addition in history was a series of 71 paintings illustrating events in American history, by the late J. L. Gerome Ferris, presented by Mrs. Ferris. Twenty-three scientific expeditions relating to the Museum were in the field during the year, bringing back valuable material for study and exhibition. The number of visitors for the year totaled 1,630,030.

National Gallery of Art.—Two special exhibitions were held during the year—one a collection of paintings made in Spain by Wells M. Sawyer and the other an exhibition in honor of the bicentennial of the birth of George Washington, which consisted of paintings, sculpture, plans of Washington City, etc., and was held under the auspices of the United States Bicentennial Commission and the National Commission of Fine Arts. Accessions of art works included a number of portraits, including those of Henry Ward Ranger and Rear Admiral Richard Evelyn Byrd, and two water-color paintings by William Spencer Bagdatopoulos. Fifteen paintings were purchased by the Council of the National Academy of Design; under Mr. Ranger's will, any of these may be claimed by the National Gallery during the 5-year period beginning 10 years after the artist's death and ending 15 years after his death.

*Freer Gallery of Art.*¹—Additions to the collections include examples of Persian bookbinding; Chinese bronze; Chinese and Persian ceramics; Chinese jade; Arabian, Persian, Armenian, and Indian manuscripts; and Chinese silver-gilt. Curatorial work has been devoted to a study of a Japanese *mandara* painting; to a study of the Indian manuscript, *Vasanta Vilāsa*; to a critical study of an ancient Armenian manuscript of the Four Gospels; and to the study of inscriptions on Buddhist stone sculptures and of inscriptions and seals on Chinese paintings. The total attendance of visitors for the year was 122,940. A full report of archeological work undertaken by the field staff of the gallery in Shansi Province, China, is now being published in Shanghai. It will be printed in both English and Chinese and will be fully illustrated.

Bureau of American Ethnology.—Much of the work of the bureau depends upon field expeditions, which obtain needed information and collections connected with its investigations of the Indians. The chief, Mr. Stirling, as a guest of the privately organized Latin American expedition, visited the Tule Indians of Panama and the Jivaros of Ecuador. Doctor Swanton had considerable success in

¹ The Government's expense in connection with the Freer Gallery of Art consists mainly in the care of the building and certain other custodial matters. Other expenses are paid from the Freer endowment funds.

locating the probable route of De Soto and Moscoso through Arkansas and Louisiana. He also recorded linguistic material among the Tunica Indians in Louisiana and continued the preparation of the handbook of the Southeastern Indians. Doctor Michelson conducted linguistic and other researches among the Cheyenne, the Fox, and the Kiowa. Mr. Harrington studied the Indians of Monterey and San Benito Counties, Calif., and investigated the Chingichngich culture of the coast of southern California. Doctor Roberts continued excavations near Allantown, Ariz., uncovering a number of pit houses, one of which, dated 797 A. D. by means of charred timbers, proved to be one of the earliest buildings of known date in the Southwest. Doctor Strong conducted excavations in the stratified deposits on the top of Signal Butte, in western Nebraska, revealing three distinct levels of occupation, the lowest evidently of great antiquity. Mr. Hewitt continued his researches on the Iroquois Indians of the United States and Canada. Mr. Walker explored certain caves in the Ozark region of north central Arkansas and mound and village sites in northern Louisiana. Miss Densmore continued her researches on Indian music, particularly among the Winnebago of Wisconsin and the Seminole of Florida.

International Exchanges.—The International Exchange Service is the official United States agency for the exchange with other countries of parliamentary documents, departmental documents, and miscellaneous scientific and literary publications. The total number of packages of such material handled by the service during the year was 759,035, an increase of about 18 per cent over last year's total. The total number of sets of United States official documents forwarded to foreign depositories is 112, and the number of copies of the Congressional Record sent to designated agencies abroad is 104.

National Zoological Park.—An expedition to British Guiana, led by the director of the park, brought back 317 live animals, including 13 species of mammals, 25 of birds, and 31 of reptiles and amphibians. Other accessions for the year totaled 900 animals. There were removed by death, exchange, and return of animals on deposit a total of 1,416, leaving the collection at the close of the year at 2,302 animals. Outstanding among the gifts of the year were the baby mountain gorilla and chimpanzee brought by Mr. and Mrs. Martin Johnson. Visitors totaled 2,169,460, including 716 groups from schools and other organizations in 22 States, the District of Columbia, and Cuba. Work has progressed on the plans for a building for small mammals and great apes. The newly completed reptile house continues to be the most popular building at the park, demonstrating that it is well worth while to exhibit animals in suitable and attractive quarters.

Astrophysical Observatory.—Volume V of the annals of the observatory was published during the year. This volume covers the work of the period 1920 to 1930, including descriptions of the stations and instruments, discussions of sources of error, methods of observation, tables of daily observations, 10-day and monthly means, and a discussion of the results of the several observing stations during the 10-year period. New instruments were designed and constructed for solar researches, those completed being a new 2-chamber water-flow pyrheliometer, a doubly dispersing spectroscope designed to observe the extreme infra-red solar spectrum between wave lengths 10 and 30 microns, and the periodometer, an instrument for investigation of periodicities in solar and terrestrial phenomena. Daily observations of the solar constant of radiation were continued at Montezuma, Chile, and Table Mountain, Calif. The station at Mount Brukkaros was closed. A volcanic eruption in Chile during the year made the atmosphere at Montezuma so hazy that satisfactory measurements of the solar constant could not be made there after April, 1932. In the search for a desirable observatory site in Africa, A. F. Moore found Mount Saint Katherine in the Sinai Peninsula in Egypt to be the most promising of those investigated.

*Division of Radiation and Organisms.*²—The carbon dioxide assimilated by wheat has been measured for light intensities varying from 78 to 1,900 foot-candles and for carbon dioxide concentrations varying from 0.004 to 0.500 per cent. A set of individual plant-growth chambers has been completed, permitting comparative observations on the effects of different wave-length distributions of light; a first experiment indicates that an excessive intensity in the less refrangible end of the spectrum, that is, the infra-red and extreme red, is accountable for much of the abnormal appearance of plants grown in artificial light. An interesting set of experiments has been conducted on the lethal effects of the ultra-violet rays upon unicellular algae. Phototropic investigations have been carried further into the blue end of the spectrum. Ultra-violet measurements of the mercury arc with the double monochromator have been carried to the point where absolute intensities can be determined with reasonable certainty. Cooperative work with the Department of Agriculture includes a study of the effects of light upon noncompetitive crop plants.

International Catalogue of Scientific Literature.—In addition to the routine work of the bureau, letters were sent by the Secretary of the Institution to all of the former regional bureaus asking whether they would again cooperate in the publication of the catalogue by supplying references to the scientific literature of their

² The Division of Radiation and Organisms is supported almost wholly by annual grants from private sources.

regions if funds could be provided to reestablish and finance the central publishing bureau. The replies so far received have been most gratifying, 16 out of 18 agreeing to cooperate in the resumption of the enterprise. It is hoped and expected that the necessary capital to resume publication, estimated at \$75,000, can be obtained.

NECROLOGY

DAVID STARR JORDAN

David Starr Jordan, chancellor emeritus of Stanford University, and associate in zoology, United States National Museum, since 1921, was born January 19, 1851, and died at his home in Menlo Park, Palo Alto, Calif., on September 19, 1931. Doctor Jordan became interested in ichthyology in the early seventies and devoted much of his time to the collection and study of fishes, to the great benefit of the collections of the National Museum. With his close associates—Copeland, Gilbert, Evermann, and others—and in cooperation with the United States Bureau of Fisheries, Doctor Jordan collected not only in the United States generally but also from Mexico to Panama and in Hawaii, Japan, and elsewhere, making full reports upon material collected, much of which was deposited in the division of fishes of the National Museum.

Over a period of 45 years (1878–1923) Doctor Jordan was author of 57 ichthyological papers, and coauthor of nearly 200 others, published in the Proceedings of the United States National Museum. In addition he was author of two bulletins of the National Museum and coauthor of three, including the monumental work on *The Fishes of North and Middle America*, in four volumes, written in collaboration with Dr. Barton Warren Evermann.

JAMES WILLIAMS GIDLEY

James Williams Gidley, assistant curator of fossil mammals in the United States National Museum, was born January 7, 1866, and died in Washington on September 26, 1931. Doctor Gidley's life work was centered in the science of vertebrate paleontology, specializing in the fossil mammalia, in which he attained great distinction. Many scientific papers, largely published by the National Museum, record the results of his investigations. He was particularly noted for his research on the fossil horses of North America and for his studies on fossil remains in the Pleistocene of Florida. Through his wide knowledge of comparative anatomy he was called into frequent consultation by students of modern mammals. Doctor Gidley entered the Government service in 1905 as a member of the scientific staff of the National Museum and had been associated with the paleontological work of the Smithsonian Institution steadily since that time.

CHARLES WALLACE RICHMOND

Charles Wallace Richmond, associate curator of birds, United States National Museum, was born in Kenosha, Wis., December 31, 1868, and died in Washington May 19, 1932. He came to Washington in 1881 and in 1888 joined the Geological Survey in its explorations in Montana. Returning from this, he became ornithological clerk in the division of economic ornithology and mammalogy in the United States Department of Agriculture. In 1892-93 he was in Nicaragua making natural-history collections, and in 1894 he was appointed assistant curator of birds in the National Museum, and in 1918 associate curator, which position he held until his death. In 1900 he was a member of the United States National Museum expedition to Puerto Rico. During the 38 years that he was affiliated with the Museum he has been a steady contributor to the publications of the Smithsonian Institution dealing with problems of ornithology and nomenclature. In these fields he was a recognized authority.

Respectfully submitted.

C. G. ABBOT, *Secretary*.

APPENDIX 1

REPORT ON THE UNITED STATES NATIONAL MUSEUM

SIR: I have the honor to submit the following report on the condition and operations of the United States National Museum for the fiscal year ended June 30, 1932:

The total appropriations for the maintenance of the National Museum for this period amounted to \$835,090, an increase of \$4,696 over those for 1931. In this year's appropriations the six separate items formerly used were combined under two headings, "Preservation of collections" and "Maintenance and operation."

The appropriations for building repairs for 1931 included four items that were for noncontinuing appropriations, amounting to \$37,500, omitted in the appropriation for 1932. Additions under maintenance and operation for 1932 amount to \$8,280, so that, omitting the items coming to \$37,500 indicated above, there is a decrease under this heading of \$29,220.

The amount available under preservation of collections was increased by \$20,416, of which \$18,600 was applied to additional personnel. Reallocations made by the Classification Board added \$2,160 to the salary rolls. Other increases amounted to \$1,816.

The sum available for printing and binding was increased by \$3,500 to care for an arrearage in the printing of manuscripts, for which further additional funds are much needed.

Requirements for additional appropriations for the National Museum follow lines indicated in previous reports. Further personnel is a question of paramount importance, as the present staff is fully occupied in the various duties that come under its scope, and there is constant need for additional assistance, as many important tasks now have to be postponed, this postponement sometimes running for several years.

This situation will be aggravated during the coming year, as under the Economy Act all funds accumulated as a result of lapses in regular positions are impounded for return to the Treasury. Moneys accumulated from such lapses have been the principal means of hiring temporary employees, so that little of the usual temporary help will be available during 1933. This means that numerous tasks will be at a complete standstill and that the arrearage at the close of the year will be considerable.

Further, the appropriations for the National Museum above the salary rolls have not been sufficient for the regular routine expenditures, these sums having been supplemented by accumulations from lapses due to temporary vacancies in regular positions on the salary roll. Under the Economy Act, as stated above, these funds are all impounded for return to the Treasury, so that the Museum in 1933, in addition to its situation with regard to temporary help, will find itself more than \$10,000 short of the funds necessary for regular routine expenditures.

Curtailment in appropriation for printing and binding for the fiscal year 1933 has placed the National Museum in a situation where the usual publications can not be issued. This will result in the postponement of many valuable papers whose contents should be made available for general public use.

ADDITIONS TO THE NATURAL HISTORY BUILDING

In the report for last year there was mention of the provision in the second deficiency bill for 1931 of an appropriation of \$10,000 for the preparation of preliminary plans for additions to the Natural History Building. It will be recalled that the extension of the Natural History Building, through wings on the east and west ends, at a cost of \$6,500,000, was authorized in the Smoot-Elliott bill, approved by the President on June 19, 1930. The executive committee of the Board of Regents selected the Allied Architects (Inc.) of Washington to make the necessary plans. The work has progressed rapidly and efficiently under the direction of Nathan Wyeth, so that these plans are now in hand.

An estimate for \$1,200,000 for a first appropriation to begin construction was included in the items submitted to the Bureau of the Budget for the fiscal year 1933, it being considered that this would suffice for excavation, foundations, and similar items, with the expectation that contracts would be made covering the continuance of the work. Due to the financial situation which arose and the necessary restriction that this imposed on the National Budget, it was not practicable to include this item in the estimates finally submitted to the Congress, nor was there later opportunity to consider it favorably. The matter has rested at this point pending more favorable opportunity.

It is highly important that construction should be begun as soon as financial conditions will permit. The addition in space that these new wings will bring is seriously needed, since the present Museum buildings are so badly crowded as to interfere with logical exhibition and storage collections, and there can be no expansion. The matter is particularly important in view of the many excellent

specimens that are constantly offered that form highly desirable additions to the national collections. Many expedients are adopted to provide additional storage facilities, but we are about at the end of our resources in this respect. It must be anticipated that more than two years will be required before the new area is ready for occupancy after construction is begun, so that work on the wings should commence as soon as practicable.

Final completion of the additions to the Natural History Building will provide properly for the Museum's needs in one direction, but other collections require more adequate housing than can be given them with the existing structures. The great collections in engineering, aviation, textiles, history, and associated fields are at present in the old Museum Building, constructed in 1881 at a cost of \$225,000, and in a temporary building south of the Smithsonian Building that houses most of the aircraft. Both buildings are crowded to such an extent that many desirable objects offered for the national collections can not be accepted because there is no room for them. Plans should be drawn as soon as possible for a large building to house the collections concerned with arts and industries, including aircraft, that will provide proper facilities for these important collections. There should be, further, a separate building for the great historical collections, in which there are found such objects as relics of Washington, Lincoln, and many other illustrious Americans; the original Star-Spangled Banner; the great series of costumes, particularly those of the wives of the Presidents; and many other objects of pride to our Nation, which should be displayed in proper form for the thousands of visitors who come annually to Washington.

COLLECTIONS

Additions to the collections of the National Museum during the fiscal year amounted to 157,870 individual specimens, a number considerably less than that of the last few years but one that must be considered normal, since in previous accounts there had been included large private collections coming as gifts or extended series of specimens from prolonged explorations in the field. Materials of various kinds received for examination and report amounted to 12,060 lots. Gifts of duplicate materials to schools and other educational organizations included 6,299 specimens, while exchanges of duplicate materials with other institutions and with individuals amounted to 11,621 specimens, for which there were received in return material needed for our collections. Loans to scientific workers outside of Washington totaled 36,639 specimens.

Following is a digest of the more important accessions for the year in the various departments and divisions of the Museum:

Anthropology.—A plaster cast of the famous bison carved in clay by Upper Paleolithic sculptors from the cave of Tuc d'Audoubert, Ariège, France, was obtained through arrangements made by J. Townsend Russell, and purchased and presented by the Old World archeology fund administered by the Smithsonian Institution. There came also a valuable collection of stone artifacts of Aurignacian age from three localities in the French Pyrenees collected by Mr. Russell as field director, under the Smithsonian Institution, of the Franco-American Union for Prehistoric Research in France. There were further collections of artifacts from several prehistoric sites in Europe and North Africa presented by Mr. Russell from his own collections. In Alaska Dr. Aleš Hrdlička collected on Kodiak Island a series of stone, bone, and wooden implements of a type not previously known, and from the region about Bristol Bay and from Kodiak Island an important series of human skeletons. M. W. Stirling forwarded a large collection of costumes and implements from the Indians of Panama, with additional materials from northwestern South Africa. From Nigeria and the Gold Coast of Africa, C. C. Roberts sent further collections of native materials, including pottery, textiles, brass castings, and many other objects. Through Mrs. Charles D. Walcott there were obtained from Hawaii several ancient poi bowls cut from wood, which are new to the Museum's collections.

Biology.—An interesting collection of birds, mammals, reptiles, and plants was obtained by Mrs. L. O. Sordahl while at the solar observatory of the Smithsonian Institution on Mount Brukkaros in Southwest Africa. This arid region is one that has been little visited by naturalists and one from which the National Museum has had little material previously. Dr. Hugh M. Smith, fisheries adviser to the Government of Siam, forwarded further collections of birds, mammals, reptiles, fish, and mollusks, so that the series from Siam is of steadily growing importance. W. G. Sheldon and Richard Borden presented an important collection of mammals made in British Columbia from regions which have not previously been represented in the Museum. These gentlemen are continuing work in that area during the coming year, and further material may be expected. The division of birds obtained 23 genera and 340 forms new to its collections, a considerable number coming from Africa through funds supplied by the late Marcus Daly. A huge specimen of the ocean sunfish estimated to weigh about 1,200 pounds, captured in nets of the Bayhead Fisheries (Inc.), off the coast of New Jersey, was presented through the Edward C. Worden Laboratory of Millburn, N. J. Additions to the collections of plants have included important series from South America collected by E. G. Holt along the Brazilian-Venezuelan frontier, presented by the National Geographic

Society, and further collections from eastern Peru received as a gift from G. Klug, of Iquitos, Peru.

Geology.—Through the income of the Roebling fund of the Smithsonian Institution there were secured a number of valuable accessions, among them a nugget of gold weighing 81 ounces troy from Plumas County, Calif.; an example of leaf gold; specimens of rare uranium minerals; and two flawless crystals of aquamarine. To the Canfield Collection there were added large exhibition slabs of crystal dolomite, on which there are crystals of other interesting minerals, and a large mass of smithsonite from New Mexico. Under the Chamberlain fund there have been obtained a number of interesting specimens of coral, illustrating its use as gem material. Additions to the Isaac Lea collection include a carved vase of Siberian malachite, and some fine opals from Mexico.

Through field investigations financed by the Smithsonian Institution there were obtained important collections of fossils, particularly of mammals. Mr. Gilmore collected a considerable part of a large creodont, three partial skeletons of *Coryphodon*, fossil turtles, several skulls of a primitive alligator (*Allognathosuchus*) and some remains of the giant flightless bird *Diatryma*. N. H. Boss collected a series of fossil horse bones from the quarry near Hagerman, Idaho, that included 32 skulls and 4 partly articulated skeletons, adding measurably to our series of the Pliocene horse *Plesippus shoshonensis*. The United States Geological Survey transferred several sets of rocks and ores and valuable collections of fossil plants. The fourth shipment of the private collection of Dr. A. Foerste, numbering about 10,000 specimens, came during the year as a gift. Through the Springer fund there were obtained some excellently preserved echinoids from the Cretaceous deposits of Texas, and several slabs of slate from the Devonian of Germany carrying fine specimens of crinoids preserved in pyrite.

Arts and Industries.—In the division of engineering a full-size model of a soft-coal mine was under construction, for which several companies contributed materials such as safety lamps, miners' belts, mine cars, and mine timbers, that will make a most attractive exhibit when assembled. The section of aeronautics received from the Autogiro Co. of America the first autogiro to fly in this country—an invention of Juan de la Cierva. This interesting machine was flown to Washington by James Ray, vice president of the Autogiro Co. of America, and was landed in a narrow space on the lawn in front of the Arts and Industries Building, where it was formally presented for the Museum. The Packard Motor Car Co. presented to the National Aircraft Collection the original Packard-Diesel aircraft engine. For the collection illustrating the development of land

transportation there was received an electric brougham of about the year 1900, a gift from Mrs. Herbert Wadsworth.

For the collection showing the development of time keeping the city of Frederick, Md., presented a tower-clock movement made about 1791 that was continuously in use as the town clock until a few years ago.

From Mrs. Daniel Gardner the Division of Textiles received a notable series of specimens illustrating the textile art and related subjects of the early nineteenth century. These included hand-woven blankets, bed linens made from hand-spun yarns, Paisley and India shawls, coverlets, and baskets. Through exchange with Yale University, School of Forestry, the wood collections received a set of 116 Liberian woods collected where extensive forests were being cleared for rubber planting.

History.—The division of history obtained as its outstanding addition a series of 71 paintings by the late J. L. Gerome Ferris, presented by Mrs. Ferris, the set representing the life work of this well-known American artist. The pictures illustrate notable events in American history from the time of the discovery to the World War; a number deal with the career of George Washington. The personnel of the Eighty-first Division, A. E. F., presented a portrait of Maj. Gen. Charles J. Bailey, painted by Joseph Cummings Chase. The Chase Collection of A. E. F. portraits in the National Museum now includes 48 paintings. For the antiquarian collections Mrs. Eleanore Daughaday Hertle, through her husband, Louis Hertle, gave a topaz necklace presented to Mrs. James Monroe by her husband, James Monroe, when he was United States minister to France.

Through the Joint Committee on the Library the Congress of the United States loaned to the National Museum the Washington memorial window, a stained-glass panel by Maria Herndl representing George Washington on horseback conferring with Lafayette and Von Steuben. A large collection of chinaware, glassware, silverware, and other household objects of the early part of the nineteenth century was presented by Mrs. Daniel Gardner.

The collection of military uniforms of the World War period was augmented by a series of military uniforms and equipment of the type used by the enlisted men of the Portuguese Army contributed by the Government of Portugal through its minister in Washington.

The American Numismatic Society continued its additions to its large and interesting loan collection of coins. The philatelic collection received more than 4,000 specimens by transfer from the United States Post Office Department—chiefly sets of new issues distributed by the International Bureau of the Universal Postal Union.

MEETINGS AND RECEPTIONS

The lecture rooms and auditorium were used during the past year for 118 meetings, covering the usual wide range of activities. Full report on these will be found in the report of the United States National Museum, separately published.

CHANGES IN EXHIBITIONS

Following renovation of the Aircraft Building as a safeguard against fire, the collections in aeronautics were rearranged and the building was opened once more to the public. In the Arts and Industries Building a new case was constructed for the Star-Spangled Banner, the case being one of the largest in the Museum, displaying the entire union of this important flag. The new installation has proved most attractive, making this historic emblem one of the dominating features of the north hall, where it shows to great advantage. The naval collection shown formerly in the rotunda of the Natural History Building was transferred in the late winter and early spring to the northwest court of the Arts and Industries Building, this move bringing all of the historical collections together.

As another major feature in connection with the historical series, the Ferris collection of paintings was installed in specially built alcoves along the south side of the costumes hall. Here they make a most attractive display with specially arranged lighting. The paintings have been placed behind glass for protection.

The historical relics concerning George Washington were all assembled in the north hall, where they are shown more conveniently and attractively for visitors during the Bicentennial celebration. For the period of the Bicentennial a special exhibition, principally of statuary, was installed in the National Gallery of Art, with extension into the rotunda of the Natural History Building. The greater part of the foyer was allotted also for a temporary exhibit of the National Capital Park and Planning Commission dealing with the development of the city of Washington.

EXPLORATIONS AND FIELD WORK

Investigations in the field have included researches concerned with man, with fossil creatures of many kinds, and with various phases of living animal and plant life. The work has been carried on mainly through grants from the Smithsonian Institution, assisted by contributions from individuals, while certain projects were financed through the income of special funds under jurisdiction of the Smithsonian. A brief account of field work for the present year follows.

Through the financial assistance of Dr. W. L. Abbott, long a friend of the Smithsonian Institution, Herbert W. Krieger, curator of ethnology, carried on archeological investigations in Cuba in continuation of work of a similar nature that he has pursued for several years in Haiti and the Dominican Republic. His investigations covered a variety of sites between Camaguey and the extreme western end of the island, with additional studies on the Isle of Pines. The collections from these investigations have been considerable; they indicate important evidence in the correlation and distribution of the prehistoric human cultures of the West Indian area.

Mr. Krieger was also occupied at various times in exploring Indian village sites in the lower Potomac area not far from Washington. In the course of this work he has prepared a map showing the location of known sites and has attempted to correlate data recovered with descriptions of such sites in the works of Captain John Smith and others. The work, when completed, will result in important information, as except for the writings of Smith and Raleigh we have practically nothing in the nature of a historical description of the Indians of tidewater Virginia and of the Carolinas.

Archeological work in northern Alaska was carried on during the summer by James A. Ford and Moreau B. Chambers under the general direction of H. B. Collins, jr., who has been working in this area for several years. Mr. Chambers excavated for three months at Gambell, St. Lawrence Island, where during the summer of 1930 Mr. Collins had found an unbroken sequence of Eskimo occupation extending from an early phase of the old Bering Sea culture to the present time. Mr. Chambers's work added to the completeness of this chronological record, bringing especially further evidence of the transitional phase between the old Bering Sea and the Punuk periods.

Mr. Ford proceeded to Point Barrow, but ice conditions in the Arctic were the worst in many years, so that he did not arrive until late in August, when the ground was beginning to freeze. Arrangements were therefore made for him to stay at Barrow over the winter in order to get in a full season of excavation in 1932. During the winter he was occupied in various studies pertaining to the modern Eskimo.

Neil M. Judd, curator of archeology, was engaged in an archeological reconnaissance on the San Carlos Indian Reservation, Ariz., on behalf of the Bureau of American Ethnology. Several caves near Arsenic Spring, on the southwest slopes of the Nantac Plateau, sheltered small pueblo ruins whose associated pottery fragments suggest occupancy in the thirteenth century or later.

F. M. Setzler, assistant curator of archeology, continued work in the Big Bend region of southern Texas, an area heretofore unknown archeologically that is thought to conceal important information

relative to prehistoric contacts between the tribes of northeastern Mexico and those of the lower Mississippi Valley. Materially aided by the staff of the Plant Quarantine and Control Administration, United States Department of Agriculture, at Alpine, Mr. Setzler centered his recent explorations in the Chisos Mountains district, overlooking the Rio Grande. A number of important caves in this region were investigated and various other examinations were made that correlate with results obtained last year in Presidio County to the west.

During the past year the cooperative agreement between the Smithsonian Institution and the University of Toulouse for the excavation of prehistoric sites in France, arranged by J. Townsend Russell, collaborator in Old World archeology, as representative of the Smithsonian Institution, became formally effective. In July, 1931, as field director of the Smithsonian Institution-University of Toulouse researches in prehistory, financed by the Institution from the Old World archeology fund, Mr. Russell initiated excavations in the cave of Marsoulas, in the commune of the same name, Department of Haute-Garonne, southern France. Count Henri Begouen, professor of prehistory at the University of Toulouse, participated in the investigations as representative of the university. Exploratory soundings were also made in the near-by cave of Tarte, in the cave of Roquecourbere, one of the two sites of Solutrean age in the Pyrenees, and in the workshop of Roquecourbere. In consequence of this preliminary work a formal agreement was signed on November 27 for cooperative work between the University of Toulouse and the Smithsonian Institution in the same general region during a period of 10 years.

It is a privilege to be able thus to join with the University of Toulouse in researches which should contribute new information to our present knowledge of Paleolithic man. While the cooperative agreement provides that the rarest objects remain in France, the generosity of the University of Toulouse is apparent from the fact that it retained only two of the specimens found during the preliminary work of the season of 1931. Thus it is to be expected that representative series of artifacts will come to help fill the very considerable gaps in the National Museum's limited exhibits of European prehistory.

At the opening of the fiscal year Dr. Aleš Hrdlička, curator of physical anthropology, was engaged in anthropological and archeological investigations in Alaska that included the lower Nushagak River, Bristol Bay, the Iliamna Lake regions, portions of Kodiak Island and adjacent areas. Interesting results were obtained throughout, with especially important materials coming from

Kodiak Island, where there was found abundant evidence of a culture that shows evidence of considerable age. This shows interesting relationships on one hand to the Eskimo and on the other to the Northwest coast area. In May, 1932, Doctor Hrdlička returned to Alaska on his fifth expedition to that interesting area, centering his efforts this year on the Kodiak Island deposits discovered at the close of the season last year. Through the interest of Mrs. Charles D. Walcott he was provided with a small motorboat for use in the bays about the coast of the island.

Dr. Walter Hough, head curator of the department of anthropology, examined the archeological field opened up by Dr. Byron Cummings around Tucson, Ariz., where huge adobe walled ruins are being excavated.

Work abroad in the interests of the Springer Collection, again undertaken by Dr. R. S. Bassler, head curator of the Department of Geology, embraced a study of the crinoid collections of various museums, particularly in England, Austria, and Hungary, and explorations in certain of the classic geologic areas of these countries. The entire trip was very successful and resulted in many casts of fossil echinoderm types, particularly Silurian crinoids hitherto wanting in the collections.

Dr. W. F. Foshag, curator of mineralogy and petrology, engaged in explorations in the States of Coahuila, San Luis Potosi, Zacatecas, and Queretaro, Mexico, under the auspices of the Roebling fund of the Smithsonian Institution. Complete series of the rocks and ores of the districts visited were collected, resulting in many important additions to the Roebling Collection in the National Museum.

James Benn, junior aid in the Department of Geology, made certain collections in southern New York and northern New Jersey. Of particular interest are fine examples of fluorescent minerals obtained at Franklin Furnace, N. J.

Late in the year E. P. Henderson, assistant curator of physical and chemical geology, traveling under the Canfield fund of the Smithsonian Institution, was detailed to collect in Montana, Utah, and Colorado, with certain needs of the collections as his objective. He was accompanied by F. A. Gonyer, representing the mineralogical department of Harvard University.

For the advancement of his work on the Cambrian, Dr. Charles E. Resser, curator of stratigraphic paleontology, spent four months in a study of early Paleozoic fossils in European museums and in consultation with geologists concerning the local stratigraphy of the neighboring areas. His work began in Norway and Sweden and extended to Czechoslovakia, Poland, Estonia, Germany, and England. His major objectives were attained to a greater degree than expected,

and in addition much new material was secured for the Museum by exchange arrangements.

Dr. G. A. Cooper, assistant curator of stratigraphic paleontology, collected during his vacation, at his own expense, in classical Devonian localities in New York State. At the close of his work he presented to the Museum more than 2,500 specimens.

The field explorations of C. W. Gilmore, curator of vertebrate paleontology, covering the Miocene and Oligocene formations of southwestern Montana, and the Wasatch of the Bighorn Basin, Wyo., met with gratifying success. The material collected will fill long-existing gaps in the collections, and it is anticipated that study will reveal many undescribed forms.

Excavations were continued in the fossil-horse quarry near Hagerman, Idaho, under the direction of Norman H. Boss, chief preparator in the division of vertebrate paleontology, resulting in the recovery of 4 more or less complete articulated skeletons, 32 skulls, 48 jaws, and a vast assemblage of skeletal parts.

The Walter Rathbone Bacon traveling-scholarship under the Smithsonian Institution has been awarded for the current period to Alan Mozley for study of the land and fresh-water molluscan fauna of Siberia. Mr. Mozley left for the field in the spring of 1932 and proceeded to Tomsk, Siberia, where he intends to establish headquarters for this year's exploration. Mr. Mozley reports that he will make an expedition to the mouth of the River Ket, and later, after returning to Tomsk, will make an excursion south into the Akhmo-linsk Steppe. He reports cordial cooperation of the local authorities and scientific institutions.

Dr. J. M. Aldrich, curator of insects, collected Diptera in the Gaspé Peninsula of eastern Quebec. He obtained a large collection of flies, establishing the fact that a large number of southern species have a much wider distribution northwards than has hitherto been supposed, though the lower St. Lawrence River appears to form a sufficient barrier against the spread of the northern flies southward, as no striking forms of the Labrador fauna were found.

Dr. Paul Bartsch, curator of mollusks, with financial assistance from the Carnegie Institution of Washington, again visited the Florida Keys to examine the Cerion colonies planted during previous years to determine the effect on these mollusks of changes in environment, as well as of hybridization, a work in which the Smithsonian Institution and the Carnegie Institution have cooperated since 1912.

Gerrit S. Miller, jr., curator of mammals, traveling at his own expense, with some assistance from the Smithsonian for the hire of labor, visited Puerto Rico during March and April with the main

object of continuing his studies of the recently extinct mammal fauna of the Greater Antilles. Important localities were investigated and many specimens were obtained representing mammals, reptiles, batrachians, plants, and aboriginal artifacts.

Dr. Waldo L. Schmitt, curator of marine invertebrates, with the cooperation of the Carnegie Institution of Washington, continued a survey of the carcinological fauna of the Tortugas region at the Carnegie Marine Laboratory at Tortugas.

Dr. Hugh M. Smith, in Siam, continued explorations throughout the year, sending to the National Museum large collections of vertebrates and mollusks which have been found to include numerous forms new to science. Thanks to Doctor Smith, the Museum is assembling a most excellent representation of the life of a region from which it had previously possessed little material.

W. G. Sheldon and Richard Borden, interested particularly in mammals, arranged a 3-month trip at their own expense into north-eastern British Columbia, where they secured for the Museum a considerable collection that contains many forms of especial interest. The principal objective was to obtain specimens of a peculiar form of mountain sheep and as representative a series of other mammals as possible, in which the collectors were highly successful. The collections, including certain birds as well as mammals, have been presented to the National Museum. Thanks are due the Canadian Government for the necessary permits covering the taking of scientific specimens.

Dr. A. Wetmore, assistant secretary, visited the Bear River marshes at the northern end of Great Salt Lake, Utah, where he obtained various specimens of birds required in the Museum series. The region is one famous for its waterfowl, being now in large part included in a Federal refuge, and is an area from which the Museum has extensive collections.

BUILDINGS AND EQUIPMENT

The erection of the steel galleries in the Natural History Building for the mammal collections was completed at the end of August. A pneumatic collecting and conveying system for removing sawdust from the two woodworking rooms in the carpenter shop was installed, an important improvement long needed.

The power plant was in operation from October 5, 1931, until May 27, 1932. The consumption of coal during the year was 3,220.4 tons, at an average cost per ton of \$5.03. The total electric current produced amounted to 628,578 kilowatt-hours, at a cost of 1.65 cents a kilowatt-hour. The ice plant manufactured 424.2 tons of ice at an average cost of \$2.36 a ton.

MISCELLANEOUS

The exhibition halls of the National Museum were open during the year on week days from 9 a. m. to 4.30 p. m. and on Sundays from 1.30 p. m. to 4.30 p. m., with the exception of the Aircraft Building, which was open only on week days. All buildings remained closed during the day on Christmas and on New Year's.

Visitors for the year totaled 1,630,030, a decrease of 39,110 from the record of the preceding year, this difference being due partly to the fact that the Aircraft Building was closed on Sundays. Attendance in the several buildings was recorded as follows: Smithsonian Institution, 241,844; Arts and Industries Building, 675,435; Natural History Building, 600,535; Aircraft Building, 112,216. The average daily attendance for week days was 4,237 and for Sunday 5,927.

During the year the Museum published 10 volumes and 57 separate papers, while the distribution of volumes and separates to libraries and individuals aggregated 101,975 copies. In addition, 18,805 copies of publications issued during this and previous years were supplied in response to special requests.

In the Department of Arts and Industries the divisions of mineral and mechanical technology were consolidated on July 18, 1931, as a division of engineering, under Carl W. Mitman as curator. Dr. T. Dale Stewart was appointed assistant curator of the division of physical anthropology on July 1, 1931, and Horace G. Richards, who served as senior scientific aid in the division of mollusks from October 5, 1931, was given appointment on March 16, 1932, as assistant curator of the division. Dr. Charles L. Gazin on March 1, 1932, succeeded the late Dr. James W. Gidley as assistant curator in the division of vertebrate paleontology, and Joseph H. Riley on June 24, 1932, succeeded the late Dr. Charles W. Richmond as associate curator in the Division of Birds. Dr. C. W. Stiles was given the honorary designation of associate in zoology under the Smithsonian Institution October 1, 1931, and Dr. Maurice C. Hall was appointed to the custodianship of the helminthological collections from the same date. Dr. D. C. Graham's association with the Museum was recognized by his appointment on October 19, 1931, as collaborator in biology, an honorary title which was also extended at the same time to Dr. A. K. Fisher. Dr. C. Dwight Marsh was appointed custodian of freshwater copepods in the division of marine invertebrates on July 10, 1931, and J. Townsend Russell's honorary appointment as collaborator in Old World archeology was extended for one year from May 13, 1932.

The following employees left the service through operation of the retirement act: Charles S. Atkins, laborer; Frederick W. Wilson, guard; Evan D. Lewis, guard; and Miss K. A. Gallaher, under

library assistant. Further, under compulsory retirement for age provided as an economy measure in the legislative appropriation act for 1933, 12 employees went off the rolls at the close of the fiscal year, several having served the Museum long in positions of trust and authority. The list follows: William de C. Ravenel, administrative assistant to the secretary, with 48 years of service; Barton A. Bean, assistant curator of fishes, with 51 years of service; James G. Traylor, appointment clerk, with 50 years of service; Harry C. Taylor, chief of the paint shop, with 44 years of service; Andrew Lee Young, assistant to the engineer, with 41 years of service; Richard A. Allen, senior scientific aid in the department of anthropology, with 35 years of service; Carl A. Carlsson and Lewis Jones, guards; William Jones, under mechanic, with 23 years of service; and Charles S. Washington, Albert Strong, and James S. Peyton, laborers, with 36, 23, and 15 years, respectively.

Through death the Museum lost five workers from its active roll, as follows: Dr. Charles W. Richmond, associate curator of birds, May 19, 1932; Dr. James W. Gidley, assistant curator of mammalian fossils, September 26, 1931; William S. Frazee, guard, March 15, 1932; Michael A. Coleman, guard, May 17, 1932; Mrs. Theresa Dimmick, forewoman of charwomen, on October 18, 1931.

From its honorary list of workers the Museum lost by death Dr. David Starr Jordan, associate in zoology, on September 19, 1931, and Dr. C. Dwight Marsh, custodian of fresh-water copepods, on April 23, 1932. The Museum lost a benefactor of note by the death of Rudolf Eickemeyer, of Yonkers, N. Y., on April 24, 1932. A few years ago Mr. Eickemeyer presented the Museum with his unique collection of pictorial photographs and historical specimens relating to photography, and by his will established a trust fund of \$10,000, the income of which after the death of his widow is to be used for maintenance and collection in the section of photography.

Respectfully submitted.

ALEXANDER WETMORE,
Assistant Secretary.

Dr. C. G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 2

REPORT ON THE NATIONAL GALLERY OF ART

SIR: I have the honor to submit herewith my report on the operations of the National Gallery of Art for the fiscal year ending June 30, 1932.

The year has not been marked by any event of unusual importance or by the addition of art collections of exceptional value. The most noteworthy event of the year was the assignment of certain portions of the gallery space to the George Washington Bicentennial Commission for its exhibits of art works during 1932. Certain radical changes in the exhibition spaces were required; and since the gallery occupies the north hall of the National Museum, all changes made were directed by the officers of the Museum.

During the year much progress has been made toward the completion of the gallery card catalogues, which are (1) a comprehensive general catalogue of the art works of the Institution, not, however, including the Freer collection; (2) a portrait catalogue (275 numbers); (3) a catalogue of loans (64 numbers), and (4) a catalogue of the Ranger purchases from the beginning (99 numbers).

THE NATIONAL GALLERY OF ART COMMISSION

The eleventh annual meeting of the gallery commission was held at the Smithsonian Institution on December 8, 1931. The members present were Gari Melchers, chairman; Frank J. Mather, jr., vice chairman; W. H. Holmes, secretary; and Charles L. Borie, jr., James E. Fraser, Charles Moore, E. C. Tarbell, and Dr. Charles G. Abbot, ex officio. The following officers, whose terms expired automatically on this date, were reelected to serve during the ensuing year: Gari Melchers, chairman; Frank J. Mather, jr., vice chairman; and William H. Holmes, secretary of the commission. The following members were recommended to serve for the succeeding term of four years: James E. Fraser, Joseph H. Gest, Frank J. Mather, jr., and Edmund C. Tarbell. The death of the following members of the commission was announced: James Parmelee, on April 19, 1931; Daniel Chester French, on October 7, 1931; and W. K. Bixby, on October 29, 1931. Col. George B. McClellan, Thomas Cochran, and Paul Manship were recommended to fill the vacancies thus occasioned. (Mr. Cochran declined.)

Favorable report was made on acceptance of the following art works:

Portrait of Henry Ward Ranger, by Albert Neuhuys, presented by Frederick Ballard Williams.

Portrait of Henry Ward Ranger, by Alphonse Jongers, presented by James E. Fraser.

Painting by Emanuel Leutze (1816-1868), the preliminary sketch for his great fresco in the Capitol Building at Washington, known as *Westward the Course of Empire Takes Its Way*. Presented to William H. Seward by the artist. Bequest of Miss Sara Carr Upton.

SPECIAL EXHIBITIONS

An exhibition of paintings made in Spain and exhibited in the Salon de Exposiciones del Museo Nacional de Arte Moderno, Madrid, in 1928, as "Corners in Spain," the work of Wells M. Sawyer, was held from October 24 to November 30, 1931. It comprised 44 oil paintings and 24 water colors. Cards for the opening view were issued, and a catalogue was supplied by the gallery.

An exhibition in honor of the bicentennial of the birth of George Washington, of paintings, sculpture, plans of Washington City, etc., was opened under the auspices of the United States Bicentennial Commission and the National Commission of Fine Arts. Participating societies include the National Sculpture Society, National Capital Park and Planning Commission, National Gallery of Art, American Society of Landscape Architects, American City Planning Institute, National Society of Mural Painters, American Academy in Rome, American Institute of Architects, American Federation of Arts, and National Conference on City Planning. Invitations for the opening exercises on March 26 were issued by the commission, and a catalogue of exhibits has been made available by the District of Columbia George Washington Bicentennial Commission. The exhibition will close on Thanksgiving Day, November 24, 1932.

ART WORKS RECEIVED DURING THE YEAR

Accessions of art works by the Smithsonian Institution, subject to transfer to the National Gallery on approval of the advisory committee of the National Gallery of Art Commission, are as follows:

Portrait of Henry Ward Ranger, by Alphonse Jongers, A. N. A., formerly lent by the Council of the National Academy of Design. Gift of James Earle Fraser, New York, N. Y. (Accepted by the commission December 8, 1931.)

Portrait of Maj. Gen. Henry Tureman Allen, United States Army, and portrait of Gen. Robert Lee Bullard, LL. D., United States Army, by Seymour Stone. Gift of Chester D. Pugsley, Peekskill, N. Y.

Portrait of Rear Adm. Richard Evelyn Byrd, United States Navy (ret.), by Seymour Stone. Gift of the artist.

Two water-color paintings of British India: Peshawar City from the Fort, and Street in Ajmor, by William Spencer Bagdatopoulos. Gift of the artist.

Portrait of Dr. William H. Holmes, by E. Hodgson Smart. Gift of the artist.

John Gellatly added three framed photographs to the contents of the portfolio of the Gellatly Collection—one of himself, one of a portrait bust of himself by Serge Youriévitich, and one of the royal coat of arms of Scotland. The latter bears the label:

The great Scotch authority decided that the Gellatly family's ancestor was the Scotch King William the Lion who reigned as King of Scotland from the year 1165 to the year 1214, and as Royal blood flows through the Gellatly veins they are entitled to use as their own the Royal armorial arms of Scotland.

Portrait (full length) of John Gellatly, by Irving R. Wiles, N. A. Gift of the artist to the Smithsonian Institution "for association with the Gellatly Collection." Deposited by the Smithsonian Institution.

LOANS ACCEPTED BY THE GALLERY

A painting by George DeForest Brush, N. A., entitled "Indian Burial"; lent by Mrs. George DeForest Brush.

Marble bust of Charles Evans Hughes, Chief Justice of the United States, and plaster bust of Gen. John J. Pershing, by Moses W. Dykaar; lent by the sculptor.

Plaster bust of Percy Bysshe Shelley, English poet (1792-1822), by William Ordway Partridge (1861-1930); lent by Mrs. William Ordway Partridge.

Framed miniature of A Lady, by Alta E. Wilnot, as a good example of American miniature painting of the present time; lent by the artist.

Portrait of Gen. John J. Pershing, United States Army, and portrait of Adm. William S. Sims, United States Navy, by E. Hodgson Smart; lent by the artist.

Portrait of Mrs. Charles Eames, by S. Gambardella; lent for the summer by Mrs. A. Gordon-Cumming.

DISTRIBUTIONS

Portrait of George Washington, by Rembrandt Peale, property of Hon. Charles S. Hamlin; withdrawn by the owner.

Portrait of Alexander Hamilton, by John Trumbull, and portrait of Fisher Ames, by Gilbert Stuart; withdrawn by their owner, Henry Cabot Lodge, jr.

Bust in plaster of Calvin Coolidge, by Moses W. Dykaar, a gift of the sculptor to the gallery, and a similar bust of Gen. John J. Pershing, lent by the sculptor, were withdrawn by Mr. Dykaar for further work. The marble bust of Hon. Nicholas Longworth was delivered to the custody of the United States Capitol.

Portrait of George Washington, by Charles Willson Peale, the property of John S. Beck, Washington, D. C., and portrait of Dr. William Shippen, by Gilbert Stuart, the property of Dr. L. P. Shippen, Washington, D. C., were temporarily withdrawn by the owners for the Bicentennial exhibition of portraits of George Washington and his associates at the Corcoran Gallery of Art. It is expected that these will be returned to the gallery after the close of the celebration, November 24, 1932.

The original working model in plaster of the bronze equestrian statue of Lafayette erected in the Square of the Louvre by the school children of the United States in 1901, a gift to the gallery from the sculptor, Paul Wayland Bartlett, N. A. (1865-1925), was lent to Mrs. Bartlett for a special exhibition of her husband's works to be held at the American Academy of Letters, New York City, opening November 12, 1931, to be returned about May 1, 1932. The statue has not yet been returned to the gallery.

Four portraits—Adm. Holdup Stevens, 2d, by Robert Hinckley, and Mrs. Stevens, his wife, artist unknown; Mrs. John Bliss, artist unknown; and Hon. Eben Sage, by Chester Harding—were withdrawn by the lender, Mrs. Frederick C. Hicks, Washington, D. C.

Portrait of George Washington; withdrawn by the owner, William Patten, Rhinebeck, N. Y.

Five paintings—Madonna and Child, by Albertinelli; Portrait of Christ, by Georgioni; The Doctor's Visit, by Jan Steen; Baptism of Christ, by Tiepolo; and Small Landscape, by Gainsborough—were withdrawn from her collection by Mrs. Marshall Langhorne in November, 1931. The Entombment, by Van der Weyden, has also been withdrawn by Mrs. Langhorne to be restored and varnished.

A water-color painting, Dogwood Blossoms, by Elizabeth Muhlhofer; withdrawn by Miss Muhlhofer.

Portrait of Mrs. Charles Eames, by Gambardella, lent for the summer by Mrs. A. Gordon-Cumming, was withdrawn in the autumn.

THE HENRY WARD RANGER FUND PURCHASES

The paintings purchased during the year by the Council of the National Academy of Design from the fund provided by the Henry Ward Ranger bequest, which under certain conditions are prospective additions to the National Gallery collections, are as follows, including the names of the institutions to which they have been assigned:

Title	Artist	Date of purchase	Assignment
85. Woman in Cloak	Robert Henri, N. A.	1931 December	Museum of Brooklyn Institute of Arts and Sciences.
86. In My Studio	Leopold Seyffert, N. A.	do	Museum of Brooklyn Institute of Arts and Sciences.
87. Eagle Lake	Jonas Lie, N. A.	do	Iowa Memorial Union, State University of Iowa, Iowa City, Iowa.
88. Frances	Frederick Karl Fricseke, N. A.	do	Washington County Museum of Fine Arts, Hagerstown, Md.
89. The Black Cloud	Eugene Higgins, N. A.	do	A. A. Anderson Gallery of Art, College of William and Mary, Richmond, Va.
90. Summer	W. L. Lathrop, N. A.	1932 January	The Dudley Peter Allen Memorial Art Museum, Oberlin College, Oberlin, Ohio.
91. Joseph Pennell	Wayman Adams, N. A.	do	Addison Gallery of American Art, Phillips Academy, Andover, Mass.
92. The Fall Season	Bruce Crane, N. A.	do	University of Nebraska, School of Fine Arts, Lincoln, Nebr.
93. Street Shrine	Jerome Myers, N. A.	do	Museum of Brooklyn Institute of Arts and Sciences.
94. Fishermen	Eric Hudson, A. N. A.	do	Topeka High School, Topeka, Kans.
95. Nancy (palette-knife sketch).	Geo. DeForest Brush, N. A.	February	California Palace of the Legion of Honor, San Francisco, Calif.
96. New Year Shooter	George Luks	April	Gallery of Fine Arts, Yale University, New Haven, Conn.
97. Snow Fields	Rockwell Kent	do	The Minneapolis Institute of Arts, Minneapolis, Minn.
98. Shapes of Fear	Maynard Dixon	do	Museum of Brooklyn Institute of Arts and Sciences.
99. Easterly Coming	Charles H. Woodbury, N. A.	June	Society of Liberal Arts, Joslyn Memorial, Omaha, Nebr.

PUBLICATIONS

HOLMES, W. H. Report on the National Gallery of Art for the year ending June 30, 1931. Appendix 2, Report of the Secretary of the Smithsonian Institution for the year ending June 30, 1931, pp. 43-53.

LODGE, J. E. Report on the Freer Gallery of Art for the year ending June 30, 1931. Appendix 3, Report of the Secretary of the Smithsonian Institution for the year ending June 30, 1931, pp. 54-59.

Catalogue of paintings made in Spain and exhibited in the Salon de Exposiciones del Museo Nacional de Arte Moderno, as "Corners in Spain," the work of Wells M. Sawyer, on view in the National Gallery of Art, United States National Museum Building, October 24 to November 30, 1931. Pp. 1-9.

George Washington Bicentennial Exhibition of Commemorative Paintings, Sculpture, and the Plan of Washington, at the National Gallery of Art, Constitution Avenue at Tenth Street, Washington, D. C., March 26 to November 24, 1932. Prepared at the request of the United States George Washington Bicentennial Commission by the National Commission of Fine Arts. This catalogue is being made available by the District of Columbia George Washington Bicentennial Commission. Pp. 1-27.

The George Washington Bicentennial Frieze. Painted by a group of members of the National Society of Mural Painters to commemorate the two hundredth anniversary of the birth of George Washington, National Gallery of Art, Washington, D. C., 1932. Pp. 1-14.

Respectfully submitted.

W. H. HOLMES, *Director.*

Dr. C. G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 3

REPORT ON THE FREER GALLERY OF ART

SIR: I have the honor to submit the twelfth annual report on the Freer Gallery of Art for the year ending June 30, 1932:

THE COLLECTIONS

Additions to the collections by purchase are as follows:

BOOKBINDING

- 31.30. Persian, 16th century. Painted lacquer binding of the volume *Khusraw ū-Shirīn*, by Nizāmī. (See below under *Manuscripts*, 31.29, and *Paintings*, 31.31-31.37.)

BRONZE

- 32.13. Chinese, 3d century B. C. (?) Ch'in dynasty (?). A ceremonial food vessel with three ducks on the cover; the body has two annular handles and is ornamented with two horizontal bands of interlacing scroll design in delicate relief. Areas of green, blue, and red patination.
- 32.14. Chinese, Han dynasty (3d c. B. C.-3d c. A. D.). Fire-gilt dragon head: A terminal ornament for a chariot pole. Areas of green patination.
- 32.15-32.16. Chinese, Han dynasty. Two chocks, possibly chariot fittings, ornamented with a formal design inlaid in gold and silver.

CERAMICS

- 31.18. Chinese, 12th-13th century. Sung dynasty. Tz'ü-chou type. A tall, wide-lipped flask, glazed in cream-white, and ornamented with a wide band of carved floral design.
- 32.23. Persian, 12th-13th century. Rhages. Spouted pitcher with a bird in high relief on the handle. Ornamented with a band of figures of men and animals, in slight relief, showing traces of color and gold.

JADE

- 31.19. Chinese, Han dynasty. Oval cup, white, with flanged rim. The outer surface ornamented with a "rice-grain" pattern, the inner with delicate linear designs. The flanges are pierced.

MANUSCRIPTS

- 31.24. Arabic (Egypt), 14th century. Illuminated title leaf from a *Qur'an*. Paper.
- 31.29. Persian, 15th century. A bound book, *Khusraw ū-Shirīn*, by Nizāmī. Painted lacquer binding (see above under *Bookbinding*, 31.30), illuminated title leaf and six miniatures. (See below under *Paintings*, 31.31-31.37.)

- 32.1-32.2. Arabic (Egypt), 14th-15th century. First two leaves from a *Qur'ān*; gold and blue illuminations on paper.
- 32.3. Persian, early 16th century. A bound book, *Mihr-ū-Mushtari*, by 'Assār of Tabriz; dated to correspond with A. D. 1522. Illuminated first leaf and four miniatures. (See below under *Paintings*, 32.4-32.8.)
- 32.17. Arabic (Egypt), 16th century. The *Qur'ān*, in one volume. Text in black *naskhī*; richly illuminated; paper, untrimmed.
- 32.18. Armenian, 11th century. The Four Gospels in one volume (18th-19th century binding). Parchment leaves. Text in vertical uncials, black and golden; Ammonian sections in sloping uncials, golden. Illuminated title pages, initials, and paragraphs, and 163 miniature paintings. Color and gold.
- 32.24. Indian, 15th century, Gujarātī. An illuminated scroll: *Vasanta Vilāsa*, a poem on spring. Text in red, black, blue, and yellow; 79 miniatures. Color on cotton.

PAINTINGS

- 31.20. Indian, Mughal, 17th century. School of Jahāngir. An album leaf: *Darbar of Jahāngir*. Color and gold on paper.
- 31.21. Persian, 14th century, Mongol period. Leaf from a *Shāhnāmāh*: Siyavush taken prisoner by Afrasiyab. Color and gold on paper.
- Persian, 15th century. Two leaves from a *Lailā ū-Majnūn*:
- 31.22. The battle between the Arab chief Noufal and the tribe of Lailā;
- 31.23. Majnūn visited in the wilderness by the *sheikh* Salīm.
- Color and gold on paper.
- Indian, late 16th century. School of Akbar. Four leaves from the original MS. of the *Tarikh-i-Alfi* (Chronicle of a thousand years):
- 31.25. The capture of Baghdad by Tāhir;
- 31.26. The Imām of Baghdad brought before the Caliph on a charge of heresy, attributed to Basāwan;
- 31.27. A banquet given by the Caliph al-Mutawakkil, by Tiriyyā and Brispat;
- 31.28. Muwayyad put to death in the ice.
- Color and gold on paper.
- 31.31. Persian, 17th century. Leaf from a *Khusraw ū-Shirīn*, by Nizāmī (see above under *Manuscripts*, 31.29). An interpolated painting of a later date than the book, a *Shī'a* subject showing the Prophet and 'Alī with twelve companions. Color and gold on paper.
- Persian, 15th century. Six leaves from a *Khusraw ū-Shirīn*, by Nizāmī (see above under *Manuscripts*, 31.29):
- 31.32. Khusraw catches sight of Shirīn bathing in a pool;
- 31.33. A hunting scene;
- 31.34. The sculptor Farhād brought by Shapur into the presence of Shirīn;
- 31.35. Shirīn makes a visit to Farhād at work;
- 31.36. Khusraw returns to the castle of Shirīn;
- 31.37. An illuminated frontispiece and head piece.
- Color and gold on paper.
- Persian, early 16th century. Five leaves from a *Mihr ū-Mushtari*, by 'Assār of Tabriz. (See above under *Manuscripts*, 32.3):
- 32.4. An illuminated frontispiece;
- 32.5. Prince Mihr and his friend at school;
- 32.6. Mihr slays a lion at one blow;
- 32.7. Mihr feasted in a garden by the king of Khwarizm;

32.8. The nuptials of Mihr and Nahid.

Color and gold on paper.

32.9. Persian, 16th-17th century, Safavid school. By Aqa Riza. Lady with a fan. Color and gold on paper.

32.10. Indian, 17th century. Rājput. Pabāri, Basohli school. A lady and attendant beside a lotus pool. Color, gold and silver (oxidized) on paper.

32.11. Indian, early 19th century, Rājput. Pabāri, Kāñgrā. Dressing the bride. Color and gold on paper.

32.12. Indian, 18th-19th century. Rājput. Pabāri, Garhwāl. By Mola Rām (1760-1833). Kṛṣṇa holding the hill Govardhana to protect the people of Br̥ṇḍaban and their cattle from the rain poured down by Indra. Color and gold on paper.

32.19. Arabic (Northern Mesopotamia), middle 14th century. Leaf from a copy after the 13th century treatise on *Automata* by al-Jazarī: part of a water-clock with the figure of a man seated on a balcony, the so-called "Saladin" figure. Color and gold on paper.

Arabic, early 13th century. Baghdad school. By Abdallāh ibn al-Fadl. Three leaves from an Arabic translation of the pharmacological treatise of Dioscorides:

32.20. Two physicians preparing medicine;

32.21. Two men preparing to sow seed;

32.22. A physician and his assistant under a fruit tree. Color and gold on paper.

SILVER-GILT

31.17. Chinese, T'ang dynasty. A covered cup, ornamented with delicate line engraving.

Curatorial work within the collection has been devoted to the completion of a detailed study of a Japanese *mandara* painting (29.2); to a study of the Indian manuscript, *Vasanta Vilāsa* (32.24); to a critical study of the ancient Armenian manuscript of the Four Gospels (32.18)—a work still in progress at the time of this report; and to the study and recording of inscriptions on certain Buddhist stone sculptures and of inscriptions and seals on Chinese paintings. In the section of Near Eastern painting, translations of the text on recently acquired Persian manuscripts have been made and recorded, and the subjects of the miniatures identified. Besides these textual studies, the usual work involved in cataloguing new acquisitions in metal, jade, bronze, and painting has occupied members of the staff. The Fenollosa collection of lantern slides of Chinese, Japanese, and other Eastern subjects, numbering approximately 3,000, all without labels, as acquired by Mr. Freer in 1909, has been worked over, subjects identified as far as possible, and the slides labeled and stored. These are now available as illustrative material, in addition to the Freer collection slides.

During the year 1,155 objects and 399 photographs of objects were submitted to the curator by other institutions or by private persons for expert opinion as to their identity, provenance, or histor-

ical or esthetic value. Twenty-six inscriptions were submitted for translation. Reports on these things were made to owners or senders.

THE LIBRARY

During the year the library has been increased by 254 volumes, 32 unbound periodicals, and 41 pamphlets. In addition, 122 bulletins, reports, and catalogues were received.

Since the date of the last report the cataloguing of the library has been completed. Indexing of foreign periodical publications, including bound volumes of *Kokka* and *T'oung Pao*, has been begun.

LECTURES

Lectures offered to the public during the past year have been as follows:

In November—A series of lectures with lantern slides on The Literary Backgrounds of Islamic Painting in Persia, by Sir E. Denison Ross, of the School of Oriental Studies, London—

November 21: The Epics.

November 23: Timurid Literature.

November 25: Safavid Literature.

On Friday, January 22, an illustrated lecture on the excavations at the Tell Halaf in northern Syria, entitled "The Wonders of the Tell Halaf," by the excavator, Dr. Baron Max von Oppenheim.

On Tuesday, March 1, an illustrated lecture on The Ancient Art of Siberia, by Dr. Alfred Salmony, director of the Museum für Ostasiatische Kunst, Cologne.

ATTENDANCE

The gallery has been open every day from 9 until 4.30 o'clock, with the exception of Mondays, Christmas Day, and New Year's Day.

The total attendance of visitors coming in at the main entrance was 122,940—week days, 78,247; Sundays, 44,693. This year the average Sunday attendance was more than three times that of an average week day, 859 being the average for Sunday and 251 that for a week day. As before, the highest monthly total attendances were reached in April (14,655) and August (12,653); the lowest attendance was, as usual, in December (6,573).

The total lecture attendance was 825, with an average of 165. Together with visitors admitted to the offices on Mondays (15), the total attendance at the gallery during the year was 123,780.

There were 1,901 visitors to the offices during the year. Of these, 91 came for general information, 268 to see objects in storage, 37 to examine the building and installation, 142 to study in the library, 187 to see the facsimiles of the Washington manuscripts, 35 to get

permission to make photographs and sketches, 229 to examine or purchase photographs, 114 to submit objects for examination, 482 to see members of the staff. Fifty-four groups, ranging from 1 to 43 persons (total, 168), were given docent service, and 15 groups, ranging from 4 to 19 persons (total, 133), were given instruction in the study rooms.

FIELD WORK

At the time of this writing a full report of recent archeological work undertaken by the field staff in Shansi Province, China, is being printed by Kelly & Walsh (Ltd.), of Shanghai. It will be printed in both English and Chinese, arranged *dos-à-dos*, and illustrated with numerous plates, line drawings, and plans.

A second and more comprehensive report, dealing with all the work accomplished by the field staff since 1922, and especially with the painted pottery sites excavated around Wan Ch'üan in Shansi, will follow the first. It will include several color plates, as well as the usual illustrative material, and will also be printed in both languages by the same firm.

PERSONNEL

Since October 28, Y. Kinoshita has been employed as mounter of oriental paintings and is now permanently employed at the gallery.

On March 23, 1932, the Freer Gallery suffered a loss in the death of Levin C. Handy, who since June 1, 1922, had done all of the photographic work at the gallery.

William Acker, student assistant, having completed his studies at the University of Leyden, is on his way to Washington where he will be attached to the Freer Gallery for the next several months.

Respectfully submitted.

J. E. LODGE, *Curator.*

Dr. C. G. ABBOT,

Secretary of the Smithsonian Institution.

APPENDIX 4

REPORT ON THE BUREAU OF AMERICAN ETHNOLOGY

SIR: I have the honor to submit the following report on the operations of the Bureau of American Ethnology during the fiscal year ended June 30, 1932, conducted in accordance with the act of Congress approved February 23, 1931. The act referred to contains the following item:

American ethnology: For continuing ethnological researches among the American Indians and the natives of Hawaii, the excavation and preservation of archeologic remains under the direction of the Smithsonian Institution, including necessary employees, the preparation of manuscripts, drawings, and illustrations, the purchase of books and periodicals, and traveling expenses, \$72,640.

M. W. Stirling, chief, left New York on September 26, 1931, as a member of the Latin American expedition to South America. The first region visited by the expedition was the San Blas coast of Panama. Here Mr. Stirling spent approximately a month in making an ethnological survey of the Tule Indians. From Panama the expedition proceeded to Ecuador, where three weeks were spent in investigating archeological sites in the Andean highlands in the vicinity of Cuenca. After crossing the Andes and descending to the frontier post of Mendez, three months were spent among the Jivaro Indians of the Santiago and Marañon Rivers. The expedition crossed the mountains from Mendez to the upper Yaupe River. They then descended the Yaupe to the Santiago, passing down this river to its junction with the Marañon. Much of the time was spent living with the Jivaros in their own houses, where Mr. Stirling was able to record first-hand a considerable quantity of ethnological data. In addition to this a collection was made representing the material culture of the Indians of the region. After a short excursion up the Alto Marañon, the expedition passed through the famous Pongo Manseriche, descending by rafts to Iquitos, from which point the collections were shipped by way of the Amazon River to the National Museum. Mr. Stirling returned to Washington on April 26, 1932.

Dr. John R. Swanton, ethnologist, was in the field from November 2 to December 6, 1931, his object being the location of the route followed by De Soto and Moscoso through Arkansas and Louisiana from 1541 to 1543. He was the guest for a part of this time of Col. John R. Fordyce, of Hot Springs National Park, Ark. More suc-

cess was attained in determining the probable course of the Spaniards than had been anticipated. While in the field he also collected linguistic material from the Tunica Indians near Marksville, La. There are supposed to be only three individuals who can still use the old tongue.

Doctor Swanton devoted a large part of his time to continuing preparation of the Handbook of the Southeastern Indians, and a beginning has been made on a bulletin to include the linguistic material of the Coahuiltecan tongues now extinct. The work of copying the tribal map of the Indians of North America has been practically completed.

Dr. Truman Michelson, ethnologist, was at work among the Southern Cheyenne at the beginning of the fiscal year. The object was to restore phonetically some Cheyenne words previously extracted from Petter's Dictionary which were clearly Algonquian in origin. Measurements were taken of some 23 subjects, and a good deal of new ethnological information was obtained. Near the middle of July Doctor Michelson left for Tama, Iowa, to obtain some additional material on Fox ceremonials. Early in August he left Iowa and went among the Northern Cheyenne to restore the list of Cheyenne words mentioned above according to Northern Cheyenne phonetics. Incidentally a really representative group of Northern Cheyenne were measured. A statistical study has shown that the vault of the skull is decidedly low as compared with that of most Algonquian peoples and rather resembles the skull of the Dakota Sioux. In June, 1932, Doctor Michelson again left for the field. He succeeded in gaining some important sociological data on the Kiowa and obtained some new facts on Cheyenne linguistics, sociology, and mythology.

John P. Harrington, ethnologist, made a thorough study of the Indians of Monterey and San Benito Counties, in central California, and investigated the little known Chingichngich culture of the coast of southern California. Working with the oldest survivors of the Costanoan and Esselen speaking Indians of Monterey and San Benito Counties, Mr. Harrington found it possible by fully utilizing all the early records and vocabularies to illuminate the former life of these people and to define it as clearly as that of some of the better known western groups. The study demonstrated that this culture indicates a key region for central California ethnology, since it proved to be a connecting link between the cultures of northern and southern California. These Indians lived on a wooded mountainous coast, the northern breaking down of the great Santa Lucia Range, in a broad interior valley, known in early times as *la canada del rio de Monterey* and now as the Salinas Valley, and in the hilly

region between coast and valley, and east of the valley. The region was rich in fish, shellfish, game, and in vegetable foods and medicinal herbs. Labor was roughly divided between men and women, the men tending to the animal food and the women to the vegetable. The houses were built of poles and thatch, shaped like a half orange, with smoke hole at the top, and slightly sunk in the ground. The people lived in villages and were governed by the village chief and elders. One or more sweathouses were to be found at each village. The people hardened themselves to going the year around with little or no clothing in the mild climate, and the dense morning fogs did not keep them from rising at daylight and taking the daily morning plunge. A bride was taken to live at the house of her husband's people or to a new house built near there. A captain, or even an ordinary man, would sometimes have two or more wives, but monogamy was the rule. One of the important discoveries is that the people had clans.

From July 1 to September 22, 1931, Dr. F. H. H. Roberts, jr., archeologist, continued excavations at the site $3\frac{1}{2}$ miles south of Allantown, Ariz., where work was started in May of the previous fiscal year. The Laboratory of Anthropology of Santa Fe, N. Mex., cooperated in the project through July and August. The summer's work resulted in the excavation of the subterranean portions of 14 structures. The excavations showed that several of the dwellings had been destroyed by fire. The charred remnants of timbers lying on the floors demonstrated clearly the method of roof construction. The details were so clearly shown in one of the houses that it was restored so that visitors to the site might see what dwellings of that type were like. Two other pits were covered with shed roofs so that they will be preserved for a long time to come. The Douglass method of determination gave dates ranging from 814 to 916 A. D. On February 1 Doctor Roberts left Washington for Yucatan, having been detailed to the Carnegie Institution of Washington in the capacity of consulting archeologist. He spent 10 days at Chichen Itza, during which time he gained much first-hand information concerning the character of the ancient Mayan civilizations, and also visited Uxmal, the pyramids at San Juan de Teotihuacan, and several other important archeological sites in the vicinity of Mexico City. While in Mexico City he had the opportunity of seeing and examining the various objects found at Monte Alban by the expedition under Prof. A. Caso. Doctor Roberts left Washington on May 21 to resume his researches at the site south of Allantown, Ariz. Excavations were commenced on June 2, and by June 30 the remains of two additional pit houses had been cleared of the accumulated debris, and the remains of seven slab-lined storage cists uncovered.

In addition 15 burials belonging to the habitation group were found. One of the pit structures uncovered had been destroyed by fire, and the charred timbers furnished one of the earliest building dates thus far obtained in the Southwest, namely, 797 A. D.

On July 10, 1931, Dr. W. D. Strong entered upon his duties as ethnologist in the bureau. Early in August he left for a reconnaissance trip through central and western Nebraska, central South Dakota, and western North Dakota. Evidence of a prehistoric culture believed to pertain to the early Pawnee was followed up the Republican River and west as far as Scottsbluff. Here a very important stratified site on Signal Butte was investigated, and after arranging for complete excavation the next summer, Doctor Strong continued the survey trip up the Missouri River. Many large prehistoric villages of the sedentary tribes in this region were visited and their locations and characteristics noted for future investigation. The survey ended with a visit to the living Arikara Indians on the Fort Berthold Reservation in North Dakota. Many good informants were visited and preliminary ethnological work on the life and customs of this very important agricultural people was commenced. During the autumn and winter of 1931-32 the text and illustrations of a manuscript entitled "An Introduction to Nebraska Archeology" were prepared.

On May 25, 1932, Doctor Strong left for Lincoln, Nebr., and on June 15 excavations were commenced in the stratified deposits on the top of Signal Butte. Large collections of specimens from all three levels were secured, especially from the lowest level of occupation, which was very thick and gave evidence of great antiquity. Marked cultural differences between the three levels were apparent during the excavation work. Burials, both complete and partial, were found in the upper level, but no burials were encountered in the lowest level, though fragments of human bone were found. It is already certain that the unusual case of stratigraphy present on the summit of Signal Butte will, when the material has been studied in detail, yield clear evidence of an extensive sequence of cultural and artifact types for the high plains region of central North America.

J. N. B. Hewitt, ethnologist, completed the revision and the editing of the manuscript journal of the Swiss artist, Rudolph Friedrich Kurz, for publication by the bureau. He also made an intensive study of the internal organic structure of the Iroquois and the Huron (Wyandot) clan, which was a most important unit of social and political organization. This investigation revealed some hitherto unnoted and disregarded organic features of clan structure. The results of this study were submitted for publication. In addition he continued his work of coordinating the variant versions of traditional and ceremonial matters recorded in native text in the

Mohawk, the Cayuga, and the Onondaga vernaculars. In addition to the four myths of the Wind Gods mentioned in the previous report, five others of this series of texts were completed, as was also the paper dealing with the decipherment of an interesting series of mnemonic pictographs. Mr. Hewitt represents the Smithsonian Institution on the United States Geographic Board, and as a member of its executive committee has much active research work to do.

On May 11, 1932, Mr. Hewitt resumed his ethnological researches among the Iroquois members of the former Six Nations of Indians on the Grand River Grant, near Brantford, Ontario, Canada. His investigations began with a study of the permanency and the remaining cohesive power of the clan among these people, and of its influence, if any, on the social and political activities of these Indians to-day. He found what had been superficially apparent for some time, namely, that the clan structure and authority had become completely forgotten, and so maintained no effective guidance in social and political affairs. David Thomas, a former chief of the Cayuga and an intelligent man, of the Grand River Reservation, dictated a number of traditional and interpretative Cayuga texts dealing with certain phases of the ancient league rituals. John Buck, sr., a former Tutelo chief, supplied further information relating to the Wind Gods, and he also gave much assistance in interpreting league texts already recorded by Mr. Hewitt.

Winslow M. Walker, associate anthropologist, was in the field at the beginning of the year, exploring certain caves in the Ozark region of north central Arkansas. A large cavern at Cedar Grove yielded the burials of 12 individuals and a considerable number of artifacts and articles of rough stone, chipped flint, bone, shell, and crude undecorated potsherds heavily shell-tempered. The resemblance to the culture of the Ozark Bluff Dwellers described by M. R. Harrington is very marked. The skeletal remains indicate a long-headed people of moderate stature, the so-called "pre-Algonkin type." Three localities were found where there were petroglyphs—both carved and painted symbols and figures—but the designs at each of these sites were different and distinctive, and they could not be correlated with any of the Bluff Dweller caves.

In the middle of July Mr. Walker went to Louisiana, where for a month explorations of mound and village sites in various parts of northern Louisiana were undertaken, principally in the Red River and Mississippi Valleys. At Natchitoches, on Red River, while preparations were going on for the construction of some ponds for a new Government fish hatchery, an ancient Indian burial ground was discovered. Mr. Walker arrived in time to save some of the skeletal material and fragments of a beautiful highly decorated and polished pottery. The period from January to June was spent in

the compiling of an index of all archeological sites so far reported from the region of the lower Mississippi Valley, with maps showing the location of these sites in the States of Louisiana and Arkansas.

From the study of the material found at Natchitoches a paper has been prepared for publication entitled "Discovery of a Caddo Site at Natchitoches, Louisiana." The results of this study seem to justify the conclusion that this was the burial ground of the tribe of the Natchitoches, a branch of the Caddo, found inhabiting this location by Henri de Tonti in 1690. The beautiful polished and engraved pottery is very similar to that made by the Ouachita Indians living along the river of that name in Louisiana and Arkansas.

SPECIAL RESEARCHES

The study of Indian music was continued during the past year by Miss Frances Densmore, a collaborator of the bureau. The three outstanding results of the year's work are a study of the Peyote cult and its songs among the Winnebago Indians, an intensive study of the songs and customs of the Seminole in Florida, and the completion for publication of a manuscript entitled "Nootka and Quileute Music." In addition, numerous Pueblo songs recorded in 1930 have been transcribed and other Pueblo songs recorded. Eight manuscripts and the transcriptions of 109 songs have been submitted, together with the phonographic records and complete analyses of the songs.

Field trips were made to Wisconsin Dells in August and September, 1931. The first trip was devoted to the Pueblo work, the recording of Winnebago dance songs, and a continuance of the general study of the Winnebago. Following this a visit was made to a basket makers' camp near Holmen, Wis., where the ceremonial songs of the John Rave branch of the Peyote organization were recorded by William Thunder, a leader in the ceremony. On the second trip to Wisconsin Dells the ceremonial songs of the Jesse Clay branch of the organization were recorded by James Yellowbank, who is a leader in that branch. In September, 1931, and in June, 1932, the study of peyote was continued with Winnebago Indians.

On November 6, 1931, Miss Densmore arrived in Miami, Fla., to resume a study of the Seminole Indians begun in January. During the early part of her stay the work was conducted in the Seminole villages at Musa Isle and Dania and in three camps on the Tamiami Trail between Miami and Everglades. Sixty-five songs were recorded by Panther (known as Josie Billie), a leader in the Big Cypress band of the tribe. He is a medicine man in regular practice, and his work was sometimes interrupted by his attendance upon the sick.

Early in February Miss Densmore went to Fort Myers and made a trip to remote villages in the Everglades under the guidance of Stanley Hanson of that city. Then she went to the region west of Lake Okeechobee and recorded 125 songs at Brighton from Billie Stuart, a leader of singers in the Cow Creek group of Seminoles. Returning to Miami, work was resumed at Musa Isle. Additional songs were recorded by Panther, and an important tradition was related by Billie Motlo, one of the few remaining old men of the tribe.

MISCELLANEOUS

Seven bulletins of the bureau were issued during the year; for a list of these see the report on publications, Appendix 11.

In the library there were accessioned during the year 400 volumes, 150 pamphlets, and 3,400 serials. For further details see the report on the library, Appendix 10.

COLLECTIONS

Accession No.

115902. Collection of archeological material collected by M. W. Stirling at various sites in Alabama and Florida in 1931. (148 specimens.)
114568. Archeological and skeletal material collected for the Bureau of American Ethnology by F. M. Setzler from various sites in Texas in 1931. (69 specimens.)
115562. Archeological and ethnological objects collected for the Bureau of American Ethnology by Neil M. Judd on the San Carlos Indian Reservation, Gila County, Ariz. (49 specimens.)
115827. Specimens of shell from Horrs Island, Fla., collected by M. W. Stirling in 1931. (3 specimens.)
117184. Archeological material collected in 1931 by W. M. Walker from caves and rock shelters in the Ozark region of north central Arkansas, occupying portions of Searcy and Marion Counties. (23 specimens.)

During the course of the year information was furnished by members of the bureau staff in reply to numerous inquiries concerning the North American Indians, both past and present, and the Mexican peoples of the prehistoric and early historic periods. Various specimens sent to the bureau were identified and data on them furnished for their owners.

Personnel.—Dr. William Duncan Strong was appointed as ethnologist on the staff of the bureau on July 10, 1931. Miss Marion Illig was appointed as junior stenographer on September 1, 1931. De Lancey Gill was retired as illustrator on June 30, 1932, by operation of the economy bill.

Respectfully submitted,

M. W. STIRLING, *Chief.*

Dr. C. G. ABBOT,

Secretary, Smithsonian Institution.

APPENDIX 5

REPORT ON THE INTERNATIONAL EXCHANGE SERVICE

SIR: I have the honor to submit the following report on the operations of the International Exchange Service during the fiscal year ending June 30, 1932:

The congressional appropriation for the support of the service during 1932 was \$54,060, an increase of \$1,250 over that for 1931. Of this increase, \$1,000 was for freight and \$250 for boxes. The Institution received as repayments from departmental and other establishments \$5,056.23, making the total resources available during the year \$59,116.23.

The total number of packages received for distribution through the service, from both domestic and foreign sources was 759,035, an increase over the previous year of 117,697, or about 18 per cent. The greater part of this increase was in the parliamentary documents forwarded abroad.

The publications sent and received by the service are classified as parliamentary documents, departmental documents, and miscellaneous scientific and literary publications. The number and weight of packages containing the publications coming under these headings are as follows:

	Packages		Weight	
	Sent	Received	Sent	Received
United States parliamentary documents sent abroad.....	362,377	-----	<i>Pounds</i> 118,433	<i>Pounds</i> -----
Publications received in return for parliamentary documents.....	-----	11,974	-----	31,674
United States departmental documents sent abroad.....	188,971	-----	155,759	-----
Publications received in return for departmental documents.....	-----	7,974	-----	25,043
Miscellaneous scientific and literary publications sent abroad.....	146,866	-----	227,425	-----
Miscellaneous scientific and literary publications received from abroad for distribution in the United States.....	-----	40,873	-----	102,316
Total.....	698,214	60,821	501,617	159,033
Grand total.....	759,035		660,650	

It will be seen from the foregoing table that about 75 per cent of the work of the office during the year has been conducted in behalf of United States governmental establishments.

The total number of boxes used in dispatching consignments abroad was 2,652, a decrease of 350 from the preceding year. Of these boxes, 605 were for the foreign depositories of full sets of

United States governmental documents, and the remainder (2,047) were for distribution to miscellaneous establishments and individuals.

While the Smithsonian Exchange Service, as a rule, transmits its consignments to other countries in boxes, it is more economical to forward certain shipments direct to their destinations by mail, and during the year the number of packages sent abroad in this manner was 85,435, an increase of 8,826 over the number mailed last year. The decrease in the number of boxes forwarded abroad in 1931 and 1932 and the increase in the number of packages transmitted by mail during the same period were due to the sending since January 1, 1931, of the greater part of the packages for British correspondents direct by mail.

FOREIGN DEPOSITORIES OF GOVERNMENTAL DOCUMENTS

The total number of sets of United States official documents forwarded to foreign depositories is 112, 62 full and 50 partial.

The full set of official documents sent to the Prefecture of the Seine has, at the request of the Library of Congress, been discontinued and forwarded to the American Library in Paris. The partial set of documents sent to Bengal is now addressed: "Assistant Secretary to the Government of Bengal, Department of Education, Writers' Buildings, Calcutta." The series of governmental documents sent to Northern Ireland are now addressed to the "Superintendent of His Majesty's Stationery Office, Custom House, Belfast." A list of the depositories is given in the report for 1931.

INTERPARLIAMENTARY EXCHANGE OF THE OFFICIAL JOURNAL

The following have been added to the list of those establishments receiving copies of the daily issue of the Congressional Record: Office Nationale du Commerce Extérieur, Paris; Reichsfinanzministerium, Berlin; Biblioteca Apostolica Vaticana, Vatican City. These three new depositories, after allowing for the elimination of the set sent to Barcelona, which was discontinued, make the total number of copies of the Congressional Record forwarded to foreign depositories 104.

The depository of the Record in Aracaju, Brazil, has been changed to Bibliotheca Publica de Sergipe, Aracaju. For a list of the states taking part in the immediate exchange of the official journal, together with the names of the establishments to which the Record is mailed, see the report for 1931.

A list of the agencies abroad through which the distribution of exchanges is effected is given below. Most of these agencies forward consignments to the Institution for distribution in the United States.

LIST OF EXCHANGE AGENCIES

- ALGERIA, via France.
- ANGOLA, via Portugal.
- ARGENTINA: Comisión Protectora de Bibliotecas Populares, Calle Callao 1540, Buenos Aires.
- AUSTRIA: Internationale Austauschstelle, Bundeskanzleramt, Herrengasse 23, Vienna I.
- AZORES, via Portugal.
- BELGIUM: Service Belge des Échanges Internationaux, Rue des Longs-Chariots, 46, Brussels.
- BOLIVIA: Oficina Nacional de Estadística, La Paz.
- BRAZIL: Serviço de Permutações Internacionais, Bibliotheca Nacional, Rio de Janeiro.
- BRITISH COLONIES: Crown Agents for the Colonies, London.
- BRITISH GUIANA: Royal Agricultural and Commercial Society, Georgetown.
- BRITISH HONDURAS: Colonial Secretary, Belize.
- BULGARIA: Institutions Scientifiques de S. M. le Roi de Bulgarie, Sofia.
- CANADA: Sent by mail.
- CANARY ISLANDS, via Spain.
- CHILE: Servicio de Canjes Internacionales, Biblioteca Nacional, Santiago.
- CHINA: Bureau of International Exchange, Academia Sinica, 331 Avenue du Roi Albert, Shanghai.
- COLOMBIA: Oficina de Canjes Internacionales y Reparto, Biblioteca Nacional, Bogotá.
- COSTA RICA: Oficina de Depósito y Canje Internacional de Publicaciones, San José.
- CUBA: Sent by mail.
- CZECHOSLOVAKIA: Service Tchecoslovaque des Échanges Internationaux, Bibliothèque de l'Assemblée Nationale, Prague 1-79.
- DANZIG: Amt für den Internationalen Schriftenaustausch der Freien Stadt Danzig, Stadtbibliothek, Danzig.
- DENMARK: Service Danois des Échanges Internationaux, Kongelige Danske Videnskabernes Selskab, Copenhagen.
- DUTCH GUIANA: Surinaamsche Koloniale Bibliotheek, Paramaribo.
- ECUADOR: Ministerio de Relaciones Exteriores, Quito.
- EGYPT: Bureau des Publications, Ministère des Finances, Cairo.
- ESTONIA: Riigiraamatukogu (State Library), Tallinn (Reval).
- FINLAND: Delegation of the Scientific Societies of Finland, Helsingfors.
- FRANCE: Service Français des Échanges Internationaux, 110 Rue de Grenelle, Paris.
- GERMANY: Amerika-Institut, Universitätstrasse 8, Berlin, N. W. 7.
- GREAT BRITAIN AND IRELAND: Messrs. Wheldon & Wesley, 2, 3, and 4 Arthur St., New Oxford St., London W. C. 2.
- GREECE: Bibliothèque Nationale, Athens.
- GREENLAND, via Denmark.
- GUATEMALA: Instituto Nacional de Varones, Guatemala.
- HAITI: Secrétaire d'État des Relations Extérieures, Port-au-Prince.
- HONDURAS: Biblioteca Nacional, Tegucigalpa.
- HUNGARY: Hungarian Libraries Board, Budapest, IV.
- ICELAND, via Denmark.
- INDIA: Superintendent of Stationery, Bombay.

- ITALY: R. Ufficio degli Scambi Internazionali, Ministero dell' Educazione Nazionale, Rome.
- JAMAICA: Institute of Jamaica, Kingston.
- JAPAN: Imperial Library of Japan, Tokyo.
- JAVA, via Netherlands.
- KOREA: Sent by mail.
- LATVIA: Service des Échanges Internationaux, Bibliothèque d'État de Lettonie, Riga.
- LIBERIA: Bureau of Exchanges, Department of State, Monrovia.
- LITHUANIA: Sent by mail.
- LOURENÇO MARQUEZ, via Portugal.
- LUXEMBURG, via Belgium.
- MADAGASCAR, via France.
- MADEIRA, via Portugal.
- MEXICO: Sent by mail.
- MOZAMBIQUE, via Portugal.
- NETHERLANDS: International Exchange Bureau of the Netherlands, Royal Library, The Hague.
- NEW SOUTH WALES: Public Library of New South Wales, Sydney.
- NEW ZEALAND: Dominion Museum, Wellington.
- NICARAGUA: Ministerio de Relaciones Exteriores, Managua.
- NORWAY: Service Norvégien des Échanges Internationaux, Bibliothèque de l'Université Royale, Oslo.
- PALESTINE: Hebrew University Library, Jerusalem.
- PANAMA: Sent by mail.
- PARAGUAY: Sección Canje Internacional de Publicaciones del Ministerio de Relaciones Exteriores, Estrella 563, Asunción.
- PERU: Oficina de Reparto, Depósito y Canje Internacional de Publicaciones, Ministerio de Fomento, Lima.
- POLAND: Service Polonais des Échanges Internationaux, Bibliothèque Nationale, Warsaw.
- PORTUGAL: Secção de Trocas Internacionaes, Biblioteca Nacional, Lisbon.
- QUEENSLAND: Bureau of Exchanges of International Publications, Chief Secretary's Department, Brisbane.
- RUMANIA: Bureau des Échanges Internationaux, Institut Météorologique Central, Bucharest.
- RUSSIA: Academy of Sciences, Leningrad.
- SALVADOR: Ministerio de Relaciones Exteriores, San Salvador.
- SIAM: Department of Foreign Affairs, Bangkok.
- SOUTH AUSTRALIA: South Australian Government Exchanges Bureau, Government Printing and Stationery Office, Adelaide.
- SPAIN: Servicio de Cambio Internacional de Publicaciones, Paseo de Recoletos 20, Madrid.
- SUMATRA, via Netherlands.
- SWEDEN: Kongliga Svenska Vetenskaps Akademien, Stockholm.
- SWITZERLAND: Service Suisse des Échanges Internationaux, Bibliothèque Centrale Fédérale, Berne.
- SYRIA: American University of Beirut.
- TASMANIA: Secretary to the Premier, Hobart.
- TRINIDAD: Royal Victoria Institute of Trinidad and Tobago, Port-of-Spain.
- TUNIS, via France.
- TURKEY: Robert College, Istanbul.

UNION OF SOUTH AFRICA: Government Printing Works, Pretoria, Transvaal.

URUGUAY: Oficina de Canje Internacional de Publicaciones, Montevideo.

VENEZUELA: Biblioteca Nacional, Caracas.

VICTORIA: Public Library of Victoria, Melbourne.

WESTERN AUSTRALIA: Public Library of Western Australia, Perth.

YUGOSLAVIA: Ministère des Affaires Étrangères, Belgrade.

Respectfully submitted.

C. W. SHOEMAKER,

Chief Clerk, International Exchange Service.

Dr. CHARLES G. ABBOT,

Secretary, Smithsonian Institution.

APPENDIX 6

REPORT ON THE NATIONAL ZOOLOGICAL PARK¹

SIR: I have the honor to submit the following report on the operations of the National Zoological Park for the fiscal year ending June 30, 1932:

The regular appropriation made by Congress for the maintenance of the park was \$255,540—an increase of \$34,020 over 1931. Of this amount, \$4,500 was made immediately available upon the approval of the act on February 23, 1931, for the construction of quarters to house the Victor J. Evans Collection. In addition, \$4,500 was appropriated and made available upon approval of the act for the preparation of plans and specifications for the small mammal house, the next unit in the building program for the development of the Zoo.

ACCESSIONS

Gifts.—Chief among the gifts this year are Okero and Teddy, the baby mountain gorilla and chimpanzee, brought by Mr. and Mrs. Martin Johnson. These two animals are being raised together and constitute one of the most attractive exhibits in the park. The receipt of the mountain gorilla made it possible to exhibit both the lowland and mountain forms of this rare group. Samuel Kress, of the United Fruit Co., of Costa Rica, has continued his interest and sent a fine jabiru stork and a peccary. R. E. Stadelman, of the Serpenterium at Tela, Honduras, presented the park with Chanchó, a white-lipped peccary, as well as a number of other interesting specimens. Vincent Astor, of New York City, presented two Galapagos iguanas. Acquisitions under the proceeds from the Frederic D. Barstow fund, which first became available for use this year, made possible the accession of a pair of tricolored squirrels, highly colored, active, and interesting little animals from the Malay Peninsula. The proceeds from the Frances Brinklé Zerbe Memorial Fund were used for keeping the aquarium section stocked.

NATIONAL ZOOLOGICAL PARK EXPEDITION

With funds provided especially in the regular appropriation act for the park, the director, accompanied by Assistant Head Keeper

¹The complete list of animals in the collection, usually printed with this report, has had to be omitted this year owing to shortage of printing funds. Mimeographed copies of the list may be obtained by writing to the Director, National Zoological Park, Washington, D. C.

F. O. Lowe, sailed from New York July 22, 1931, for Georgetown, British Guiana. Collecting was carried on in two general regions—the Pomeroon and Mackenzie districts—and although the earlier portion of the trip was a disappointment, 317 specimens were successfully landed at the Zoo on October 11, 1931. These comprised 13 species of mammals, 25 species of birds, and 31 species of reptiles and amphibians. This exhibit brought a number of species into the Zoo for exhibition for the first time. Surplus specimens were immediately exchanged with other zoos.

On this trip the party was assisted greatly by His Excellency Sir Edward Denham, the Governor of British Guiana; Messrs. Henderson and Rucker, of the Bauxite Co., of British Guiana; Dr. George Giglioli, himself an ardent naturalist, who presented some of his pets to the expedition; and F. M. Walcott, of Hope Estate, who gave an ocelot.

While no Surinam toads were obtained on this trip, arrangements were made which later resulted in the receipt of 90 specimens in good condition, through the kindness of Captain Laun, of the Munson Steamship Line, who brought them to New York from Paramaribo. This placed on exhibition a large group of this rare toad, and enabled us to exchange specimens for exhibition with other zoos.

DONORS AND THEIR GIFTS

Stuart Abraham, Braddock Heights, Md., copperhead.

Roy Adams, Washington, D. C., snapping turtle.

Mrs. M. W. Arps, Washington, D. C., ring-necked dove.

Vincent Astor, New York City, two Galapagos iguanas.

Charles A. Baker, 2d, Baltimore, Md., kinkajou.

Dr. Paul Bartsch, United States National Museum, Washington, D. C., Jamaican snail.

F. H. Benjamin, United States Plant Quarantine and Control Administration, Orlando, Fla., Florida cooter, Osceola snapping turtle, two Florida box turtles.

Robert L. Bieber, Potomac, Md., goat.

J. B. Bland, Washington, D. C., alligator.

Miss Blondell, Washington, D. C., tarantula.

Mr. and Mrs. J. S. C. Boswell, Alexandria, Va., California king snake, three Boyle's king snakes.

M. K. Brady, Washington, D. C., king or chain snake, 2 common fence lizards, 2 blue-tailed skinks, marbled salamander, 12 Stejneger's anolis.

C. J. Brahm, Philadelphia, Pa., Chinese mantis.

Messrs. E. J. and S. K. Brown, Eustis, Fla., coral snake, scarlet snake, water snake, two corn snakes, hog-nosed snake, chicken snake, two Florida king snakes.

Meredith and Walker Buel, Washington, D. C., common fence lizard.

Allen M. Burdett, Washington, D. C., two alligators.

C. R. Burnett, Richmond, Va., white-fronted parrot, yellow-fronted parrot.

Dr. Charles E. Burt, Southwestern College, Winfield, Kans., three slender burrowing snakes, two western ring-necked snakes, brown skink, two collared lizards, two blacksnakes, five ornate tortoises, western or blue racer.

F. G. Carnochan, New York City, canvasback duck, two mallard ducks.

- R. R. Carpenter, Wilmington, Del., curl-tail lizard.
 Bernard Cawill, Silver Spring, Md., two coyotes.
 Kenneth Clow, Washington, D. C., capuchin monkey.
 Miss Doris M. Cochran, United States National Museum, Washington, D. C.,
 2 scorpions, 22 water snakes.
 Mrs. R. Cohen, Bowie, Md., three angora goats.
 Dr. F. V. Coville, United States Bureau of Plant Industry, Washington, D. C.,
 seven chuckwallas.
 Mrs. Annie T. Craley, Washington, D. C., yellow-fronted parrot.
 Miss Amelia Crawford, Washington, D. C., alligator.
 Mrs. J. H. Cummings, Wilmington, N. C., two glass snakes, six-lined lizard,
 anolis.
 R. O. E. Davis, Washington, D. C., barred owl.
 Allen DeFord, Washington, D. C., alligator.
 Charles F. Denley, Rockville, Md., four golden pheasants.
 Miss Grace Devendorf, Washington, D. C., mynah.
 F. I. Donn, Washington, D. C., common gallinule.
 M. C. Dowling, Bethesda, Md., 11 horned lizards.
 Mrs. Bertha Duncan, Washington, D. C., red fox.
 E. W. Ehmann, Piedmont, Fla., six baldpates, six pintail ducks.
 Dr. Wm. O. Emery, United States Bureau of Chemistry and Soils, Washing-
 ton, D. C., three blind worms.
 Mrs. C. L. Emmart, Baltimore, Md., alligator.
 F. W. Engle, Washington, D. C., common boa.
 William Engle, Washington, D. C., canary.
 I. B. Faidley, Falls Church, Va., coot.
 Dr. David Fairchild, Washington, D. C., two hermit crabs.
 Mrs. R. W. Ferguson, Fernandino, Fla., two Florida skunks.
 F. T. Fitch, Buchanan, Va., duck hawk.
 H. J. Gibson, Washington, D. C., blacksnake.
 Dr. George Giglioli, Mackenzie, British Guiana, deer, curassow.
 Norman Gillilan, Washington, D. C., hog-nosed snake.
 Mrs. Goodloe, Washington, D. C., opossum.
 Alex Goodman, Washington, D. C., woodchuck.
 R. H. Gordon, Washington, D. C., horned lizard.
 W. B. Grange, United States Bureau of Biological Survey, Agassiz's tortoise,
 three horned lizards, spiny swift, spiny-tailed lizard.
 Miss Hawthorne, Washington, D. C., sparrow hawk.
 Miss L. E. Hemington, Washington, D. C., six canaries.
 Horace Hicks, Washington, D. C., DeKay's snake.
 James P. Holloway, Washington, D. C., rhesus monkey.
 C. H. Holmes, Washington, D. C., red-tailed hawk.
 R. Bruce Horsfall, Nature Magazine, Washington, D. C., corn snake.
 S. R. Hughes, Leesburg, Va., common loon.
 Mr. and Mrs. Martin Johnson, New York City, chimpanzee, mountain gorilla.
 Walter Johnson, Bethesda, Md., silver pheasant, golden pheasant, two
 lineated pheasants.
 D. C. Jonhas, Washington, D. C., box tortoise, garter snake, common anolis.
 E. S. Joseph, New York City, lung fish.
 Mr. Keith, Georgetown, S. C., 5 water moccasins, 2 blacksnakes, 2 water
 snakes, 3 copperheads, chicken snake, king or chain snake.
 C. O. King, Washington, D. C., tarantula.
 John Kitterman, Kensington, Md., two common terns.

- B. P. Klibas, Washington, D. C., hawks-bill turtle.
 R. F. Knox, Cherrydale, Va., banded rattlesnake.
 Sam Kress, Port Limon, Costa Rica, jabiru, collared peccary.
 James LaFontaine, Washington, D. C., great horned owl.
 Miss Catherine Larner, Whitehall, N. Y., brown capuchin.
 S. E. Laurell, Washington, D. C., patas monkey.
 Mrs. F. C. Lincoln, Takoma Park, Md., opossum.
 Mrs. John Linder, Washington, D. C., two alligators.
 Robert Locke, Washington, D. C., alligator.
 Thomas H. Loyd, jr., Washington, D. C., West Indian tree frog.
 John L. Lucas, Washington, D. C., kangaroo rat.
 John C. Lyddams, Washington, D. C., alligator.
 Van Allen Lyman, Washington, D. C., scorpion.
 Mrs. J. R. Malloch, Ballston, Va., raccoon.
 G. Manos, Washington, D. C., four opossums.
 George E. Mattingly, Washington, D. C., pied-billed grebe.
 E. A. McIlhenny, Avery Island, La., 2 anhingas, 4 snowy egrets, 2 Louisiana herons.
 Kenneth Meyers, Takoma Park, Md., common skink.
 G. S. Miller, jr., United States National Museum, Washington, D. C., four Puerto Rican snails.
 James Miller, Washington, D. C., mink.
 Mrs. Rose L. Miller, Washington, D. C., ferret.
 W. W. Minear, Quincy, Ill., 14 blacksnakes, 19 water snakes, 8 garter snakes, 8 banded rattlesnakes, 4 leopard snakes.
 Dewey Moore, United States Bureau of Plant Industry, Indio, Calif., 2 giant hairy scorpions, sidewinder rattlesnake, 2 desert rattlesnakes, California bull-snake, 3 lizards, 4 scorpions.
 Dr. G. K. Noble, American Museum of Natural History, New York City, two southern ctenosaurs.
 Dr. H. C. Oberholser, United States Bureau of Biological Survey, Washington, D. C., two whistling swans.
 William O'Brien, Washington, D. C., double yellow-head parrot.
 Dr. S. Logan Owens, Washington, D. C., two yellow-naped parrots.
 Mrs. A. N. Pack, Princeton, N. J., raccoon.
 J. R. Page, jr., Greensboro, N. C., Florida diamond-back rattlesnake.
 Axel Pedersen, Washington, D. C., woodchuck.
 S. F. Perkins, Washington, D. C., two king snakes, water snake, blacksnake.
 A. L. Pflueger, North Miami, Fla., two diamond-back turtles, four Florida box turtles.
 Philadelphia Zoological Park, Philadelphia, Pa., three soft-shell turtles.
 Polly's Tea Room, Alexandria, Va., two raccoons, skunk, ocelot, collared peccary, great horned owl, three barred owls, crab-eating macaque, African gray parrot.
 Carlos Quiros, Port Limon, Costa Rica, emperor boa.
 Michael Rainey, Washington, D. C., alligator.
 Donald Reder, Lorton, Va., mink.
 Miss M. E. Rice, Washington, D. C., woodchuck.
 A. G. Richardson, Salem, Mass., two alligators.
 Mrs. Riley, Washington, D. C., flicker.
 H. H. Rudolph, Washington, D. C., 20 bob-whites.
 W. K. Ryan, Washington, D. C., four *Fundulus galaris*.
 San Diego Zoo, San Diego, Calif., four farallone cormorants.

William Sanders, Washington, D. C., yellow-naped parrot.
 Dr. J. E. Schillinger, United States Bureau of Biological Survey, Washington, D. C., two whistling swans.
 Mrs. I. D. Schwartz, Washington, D. C., alligator.
 Mrs. Shelby, Benning, D. C., two coyotes.
 R. D. Shields, Silver Springs, Md., capuchin monkey.
 Miss Betty Shorey, Washington, D. C., tarantula.
 Eugene Sibley, Chevy Chase, Md., two Peking ducks.
 S. G. Sifalla, Washington, D. C., Sumichrast's deer mouse and young.
 Mrs. W. H. Smith, Washington, D. C., canary.
 C. C. Sperry, United States Bureau of Biological Survey, Washington, D. C., two collared lizards.
 R. E. Stadelman, Tela Serpenterium, Tela, Honduras, white-lipped peccary, prehensile tailed-porcupine, two coral snakes, six jumping vipers.
 B. F. Stepper, Washington, D. C., 2 skinks, blue-tailed skink, 19 fence lizards, 2 red toads.
 H. G. Stewart, Seabrook, Md., spotted salamander.
 Hon. Henry L. Stimson, Washington, D. C., great red-crested cockatoo.
 Shreve Stombach, red-tailed hawk.
 J. Ralph Taylor, Washington, D. C., copperhead snake.
 Richard Taylor, Middleburg, Va., horned lizard.
 Elaine and South Trimble, Washington, D. C., flying squirrel.
 United States Bureau of Biological Survey, Department of Agriculture, Washington, D. C., laughing gull.
 United States Post Office, Dead Letter Section, alligator.
 Mrs. Elizabeth Voegele, Martinsburg, W. Va., orange-winged parrot.
 Walker Chevrolet Sales Co., Tazewell, Va., two golden eagles.
 W. Paul Ward, Fairmont, W. Va., Cooper's hawk.
 Charles Williams, marine turtle.
 G. E. Williams, Washington, D. C., red salamander.
 Larry Williams, Chevy Chase, Md., spotted salamander.
 Miss Mary Wills, Washington, D. C., horned lizard.
 G. W. Wilson, Washington, D. C., Florida gallinule.
 Paul Winthrop and C. W. Buckley, Washington, D. C., hog-nosed snake.
 Maj. Leigh F. Zerbe, United States Army, coral snake, Panama fresh-water fish.

Donor unknown, two canaries.

Births.—There were 41 mammals born, 62 birds hatched, and 45 reptiles hatched or born in the Park during the year. These include the following:

MAMMALS			
Scientific name	Common name	Number	
<i>Æpyprymnus rufescens</i>	Rat kangaroo.....	1	
<i>Axis axis</i>	Axis deer.....	2	
<i>Bison bison</i>	American bison.....	1	
<i>Canis nubilus</i>	Plains wolf.....	3	
<i>Cervus canadensis</i>	American elk.....	1	
<i>Cervus duvaucellii</i>	Barasingha deer.....	1	
<i>Cervus elaphus</i>	Red deer.....	2	
<i>Choeropsis liberiensis</i>	Pigmy hippopotamus.....	1	
<i>Dama dama</i>	Fallow deer.....	2	
<i>Equus quagga chapmani</i>	Chapman's zebra.....	1	
<i>Felis leo</i>	Lion.....	3	

Scientific name	Common name	Number
<i>Myocastor coypu</i>	Coypu.....	3
<i>Odocoileus hemionus</i>	Mule deer.....	2
<i>Odocoileus virginianus</i>	Virginia deer.....	2
<i>Ovis canadensis</i>	Rocky Mountain sheep.....	2
<i>Ovis europaeus</i>	Mouflon.....	2
<i>Phacochoerus aethiopicus massaicus</i>	East African wart hog.....	5
<i>Poephagus grunniens</i>	Yak.....	1
<i>Rusa moluccensis</i>	Molucca deer.....	1
<i>Sika nippon</i>	Japanese deer.....	3
<i>Ursus gyas</i>	Alaska Peninsula brown bear.....	1
<i>Zalophus californianus</i>	California sea lion.....	1

BIRDS

<i>Anas platyrhynchos</i>	Mallard duck.....	5
<i>Branta canadensis</i> subsp.....	Canada goose group.....	17
<i>Larus novaehollandiae</i>	Silver gull.....	22
<i>Nycticorax nycticorax naevius</i>	Black-crowned night heron.....	18

REPTILES

<i>Bothrops lanceolatus</i>	Fer-de-lance.....	15
<i>Crotaphytus collaris</i>	Collared lizard.....	6
<i>Epierates angulifer</i>	Cuban tree boa.....	3
<i>Euneetes murinus</i>	Anaconda.....	6
<i>Natrix sp</i>	Water snake.....	15

Purchases.—The most important purchases during the year were two Cape hunting dogs, two fine Aldabra tortoises, and a pair of giant anteaters.

REMOVALS

Causes of death.—When it has been thought that determination of the cause of death of certain animals might be useful, the specimens have been submitted to the pathological division of the Bureau of Animal Industry for examination. The following list shows the results of the autopsies:

MAMMALS

Artiodactyla: Congestion of the lungs, 1.

Primates: Purulent peritonitis, 1; pneumonia, 1.

BIRDS

Columbiformes: Catarrhal enteritis, 1.

The great loss of the year was the death of N'Gi, a 4½-year-old baby gorilla that had been in the Zoo from December 5, 1928, to March 10, 1932. He became ill with a bad cold, which progressed into pneumonia complicated with empyema. Dr. D. E. Buckingham, veterinarian, and his assistant, were called immediately and stayed with him day and night throughout his illness. Dr. John C. Eckhardt, M. D., a great friend of the Zoo, served as a volunteer consultant.

Through the kind interest and generosity of Mrs. Eleanor Patterson, of the Washington Herald, several X-ray pictures were made and an oxygen chamber with technicians and full equipment was brought from New York by airplane and N'Gi placed in this in an effort to save his life. He recovered somewhat, but because of the empyema a surgical operation was necessary. This was performed gratuitously by Dr. Charles Stanley White, of Washington, but the long illness had so weakened the monkey that he died shortly afterwards.

At the time N'Gi was ill, Jojo, the chimpanzee in the adjoining cage, also became ill and died. Both deaths were apparently occasioned by the same type of ailment, generally called the flu or grip, which was prevalent in Washington at that time.

Okero, the mountain gorilla, and his cage mate, Teddy, the chimpanzee, developed a slight pneumonia, but soon recovered.

ANIMALS IN COLLECTION THAT HAD NOT PREVIOUSLY BEEN EXHIBITED

MAMMALS

Scientific name	Common name
<i>Cacajou calvus</i>	White Uakari monkey.
<i>Chiropotes chiropotes</i>	Cuxio monkey.
<i>Euphractus sexcinctus</i>	Six-banded armadillo.
<i>Lycaon pictus</i>	Cape hunting dog.
<i>Metachirus fuscogriseus</i>	Allen's mouse opossum.
<i>Nyctomys sumichrasti</i>	Sumicharast's deer mouse.
<i>Sciurus humei</i>	Tricolored squirrel.

BIRDS

<i>Pitangus sulphuratus</i>	Kiskadee flycatcher.
<i>Psomocolax oryzivora</i>	Rice grackle.
<i>Sporophila lineola</i>	White-crowned seed-eater.
<i>Tinamus major</i>	Guiana giant tinamou.

REPTILES

<i>Ameiva ameiva ameiva</i>	South American swift.
<i>Anilius scytale</i>	Blunt-tailed anilius.
<i>Anolis leucophaeus</i>	Turks Island anolis.
<i>Crocodylus lacertinus</i>	Crocodile lizard.
<i>Erpetodyras carinatus</i>	Marsh snake.
<i>Erpetodyras fuscus</i>	Red and black snake.
<i>Erythrolamprus aesculapii</i>	False coral snake.
<i>Helicops angulata</i>	South American water snake.
<i>Leiocephalus inaguae</i>	Inagua Island curl-tail lizard.
<i>Leiocephalus</i> sp.....	Curl-tail lizard (Andros Island).
<i>Leptophis ahaetulla</i>	Parrot snake.
<i>Petalognathus nebulatus</i>	Blunt-head snake.
<i>Philodryas viridissimus</i>	Green tree snake.
<i>Phrynona sulphureus</i>	South American rat snake.
<i>Phrynosoma solare</i>	Crowned horned lizard.

Scientific name	Common name
<i>Plica plica</i>	Plicated lizard.
<i>Podocnemis expansa</i>	South American river tortoise.
<i>Polychrus marmoratus</i>	Marbled lizard.
<i>Pseudoboa cloelia</i>	Mussurana.
<i>Python curtus</i>	Blood python.
<i>Spilotes pullatus pullatus</i>	Tiger snake.
<i>Tantilla coronata</i>	Banded burrowing snake.
<i>Testudo elephantina</i>	Elephant tortoise.
<i>Thecadactylus rapicaudus</i>	Gecko.
<i>Xenodon severus</i>	South American puff snake.

AMPHIBIANS

<i>Gyrinophilus porphyriticus</i>	Purple salamander.
<i>Hyla septentrionalis</i>	West Indian tree frog.
<i>Pipa americana</i>	Surinam toad.

FISHES

<i>Electrophorus electricus</i>	Electric eel.
<i>Lepidosiren paradoxa</i>	South American lung fish.

INSECTS

<i>Tenodera sinensis</i>	Chinese mantis.
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MOLLUSKS

<i>Oxystyla undata</i>	Puerto Rican snail.
<i>Oxystyla undata jamaicensis</i>	Jamaican snail.

Statement of the collection

[Accessions]

	Collected by park expedi- tion	Presented	Born	Received in exchange	Pur- chased	On de- posit	Total
Mammals.....	19	57	41	-----	32	4	153
Birds.....	105	101	62	1	37	3	309
Reptiles.....	160	209	45	43	110	3	570
Amphibians.....	33	3	-----	-----	122	-----	158
Fishes.....	-----	2	-----	1	2	-----	5
Arachnids.....	-----	10	-----	-----	-----	-----	10
Insects.....	-----	3	-----	-----	-----	-----	3
Crustaceans.....	-----	2	-----	-----	-----	-----	2
Mollusks.....	-----	5	-----	-----	2	-----	7
Total.....	317	392	148	45	305	10	1,217

Summary

Animals on hand July 1, 1931.....	2,501
Accessions during the year.....	1,217
Total animals in collection during year.....	3,718
Removed from collection by death, exchange, and return of animals on deposit.....	1,416
In collection June 30, 1932.....	2,302

Status of collection

	Species	Individuals		Species	Individuals
Mammals.....	194	530	Arachnids.....	3	4
Birds.....	328	1,031	Crustaceans.....	1	3
Reptiles.....	157	549	Mollusks.....	2	27
Amphibians.....	28	101			
Fishes.....	15	57	Total.....	728	2,302

Visitors

July.....	202, 100	March.....	174, 585
August.....	216, 200	April.....	252, 000
September.....	262, 400	May.....	272, 300
October.....	241, 750	June.....	175, 200
November.....	161, 900		
December.....	48, 825	Total visitors for	
January.....	65, 800	year.....	2, 169, 460
February.....	96, 400		

The attendance of organizations, mainly classes of students, of which we have definite record, was 36,318 from 716 different schools in 22 States, the District of Columbia, and Cuba, as follows:

States	Number of persons	Number of parties	States	Number of persons	Number of parties
Alabama.....	24	1	New York.....	3,482	43
Connecticut.....	203	4	North Carolina.....	292	11
Delaware.....	218	9	Ohio.....	453	16
District of Columbia.....	10,012	202	Pennsylvania.....	7,494	153
Florida.....	75	3	Rhode Island.....	97	3
Illinois.....	65	2	South Carolina.....	31	1
Iowa.....	188	2	Tennessee.....	30	1
Kentucky.....	65	2	Virginia.....	1,995	48
Maine.....	188	6	West Virginia.....	214	6
Maryland.....	7,626	132			
Massachusetts.....	310	9	Cuba.....	14	1
Michigan.....	430	8			
New Hampshire.....	55	3	Total.....	36,318	716
New Jersey.....	2,757	50			

IMPROVEMENTS

The largest improvement of the year was the construction of approximately 11,000 feet of chain-link fence to inclose the park, taking the place of a fence that had been in use for about 31 years. In connection with the fence installation stone gate pillars and electric-welded gates were installed, and the street paving at the various entrances was adjusted in conformity with the new gates.

A series of crane runs were constructed immediately east of the bird house. The wire used was an aluminum alloy, and the installation is of an experimental nature to determine if such material will be satisfactory for this type of inclosure. Adjoining the crane runs have been built a series of nine pens for pheasants. The wire in this

case was a small-diameter copper weld, which is also partly in the nature of an experiment.

The wild-horse group has been accommodated by the construction of a series of paddocks and shelter houses on filled-in land off the main road, which now house the zebras, the kiang, and Mongolian wild horses.

The eagle cage, which had been in course of construction for some time, was completed early in the spring of 1932, and birds were immediately placed in it. Artificial rockwork forms an attractive background, and the cage as a whole is very satisfactory.

A series of outdoor cages for ostriches, rheas, emus, and cassowaries were begun and nearly completed at the end of the fiscal year. These are on the new fill back of the bird house, and will permit a much better exhibition of these large and interesting birds than has heretofore been possible. The new cages are located with due respect to the anticipated addition on the south of the bird house, so that the entire assembly will have a pleasing appearance when completed.

The Bureau of Standards, Bureau of Agricultural Engineering, and Bureau of Public Roads are assisting in determining the best material for floors for cages, and corrosion-resistant metals for cages and paddocks.

Heretofore the American waterfowl pond has been provided with water taken directly from the creek, which made the pool muddy and insanitary. In addition, the dam which raised the water in the creek sufficiently to take it into the pond resulted in a large accumulation of silt, filling the bed of the stream up to the upper ford in the Zoo, so that the ford could be used only part of the time by motorists. This combination of circumstances made it advisable to pipe city water into the duck pond, and the dam has been torn out of the creek. The water is turned on only during the night. This has resulted in a clean pool and in improvement of the conditions of the creek bed and the ford.

The Beatrice Henderson cage for birds was rewired and is now accommodating a colorful exhibit of macaws and cockatoos.

R. Bruce Horsfall, staff artist of *Nature Magazine*, has contributed to the Zoo two beautiful panoramas which he painted in the reptile house. One of these shows a Galapagos Island scene with Indefatigable Island in the distance, and makes a splendid background for the collection of tortoises. The other is a Komodo Island landscape on the wall of the cage now occupied by an assortment of large lizards. These paintings add greatly to the building's attractiveness.

NEEDS OF THE ZOO

The older buildings of temporary construction are obsolete and unsatisfactory. The urgent need of the Zoo is to continue the construction of exhibition buildings similar to the bird house and reptile house, both of which are entirely satisfactory.

Funds were provided in the last appropriation for plans and specifications for a building to house small mammals and great apes. Considerable work has been done on these plans.

The reptile house continues to be the most popular building at the Zoo, and proves that it is worth while from all points of view to exhibit animals suitably.

The police force is too small to guard the Government property for which it is responsible. An adequate force is needed.

Respectfully submitted.

W. M. MANN, *Director.*

Dr. C. G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 7

REPORT ON THE ASTROPHYSICAL OBSERVATORY

SIR: I have the honor to submit the following report on the activities of the Astrophysical Observatory for the fiscal year ended June 30, 1932:

PLANT AND OBJECTS

This observatory operates regularly the central station at Washington and two field stations for observing solar radiation on Table Mountain, Calif., and Mount Montezuma, Chile. The station at Mount Brukkaros, Southwest Africa, which was established by the National Geographic Society and was continued for a time in co-operation with the Astrophysical Observatory with funds donated by a friend of the Institution, was closed in December, 1931.¹ The observatory controls a station on Mount Wilson, Calif., where occasional expeditions are sent for special investigations, one of which is mentioned below.

The principal aim of the observatory is the exact measurement of the intensity of the radiation of the sun as it is at mean solar distance outside the earth's atmosphere. This is ordinarily called the solar constant of radiation, but the observations of past years by this observatory have proved it variable. As all life, as well as the weather, depends on solar radiation, the observatory has undertaken the continued measurement of solar variation on all available days. These measurements have now continued all the year round for 14 years. As will appear in this report, recent studies indicate that the permanent continuation of these daily solar-radiation measurements may have great value for weather forecasting. In addition to this principal object, the observatory undertakes spectroscopic researches on radiation and absorption of atmospheric constituents, radiation of special substances, such as water vapor, ozone, carbonic-acid gas, liquid water, and others, and the radiation of the other stars as well as of the sun.

WORK IN WASHINGTON

Volume V of the Annals of the Observatory was printed and distributed in the autumn of 1931. It rehearses the annals of the work from 1920 to 1930; describes the stations and instruments employed;

¹ The valuable collections of zoological and botanical specimens made in Southwest Africa by Mrs. L. O. Sordahl, wife of the director, and brought back to Washington with the instruments, are referred to above in the report of the National Museum.

discusses the sources of error inherent in the use of the bolometer, the pyranometer, and the pyrliometer, and their application to solar-constant determinations. It explains the methods now in use at the several stations for measuring solar radiation; gives long tables of pyrliometry and results of bolometry, pyrliometry, and pyranometry combined in daily determinations of the solar constant. Finally, it gives a discussion of the results of all stations for the interval 1920-1930. The agreement of the stations, the best results on the variability of the sun, and the apparent periodicities in solar variation, and their reflection in weather changes are set forth.

As delegate from the Smithsonian Institution, Doctor Abbot attended the Geographical Congress at Paris and the one hundredth anniversary meeting of the British Association for the Advancement of Science, the Faraday celebration, and the Maxwell celebration in London and Cambridge. He delivered a paper before the British Association entitled "Twenty-five Years' Study of Solar Variation."

At the conclusion of the meetings he went to Berlin, and with Doctor Martens at Potsdam he made an accurate comparison between silver-disk pyrliometers S. I. 5_{bls}, carried abroad with him, and S. I. 12, the property since 1912 of the meteorological observatory at Potsdam. Apparently no appreciable change of scale in the readings of pyrliometer S. I. 12 has occurred in the intervening 19 years. This result, confirming the stability of scale of the Smithsonian silver-disk pyrliometers, is very gratifying.

Owing to long-continued illness, Mr. Fowle's work was practically confined to the preparation for publication of a new edition of the Smithsonian Physical Tables.

Messrs. Aldrich and Kramer spent much time on instruments for pyrliometry. After long-continued efforts to perfect a new form of secondary pyrliometer of much promise, the instrument was laid aside for a time. Following the suggestion of the Russian physicist, V. M. Shulgin, a new 3-chamber water-flow pyrliometer was put in construction. The instrument comprises two pyrliometers, each nearly like that described in the *Annals of the Astrophysical Observatory*, Volume III, page 52. A common current of distilled water, carefully guarded against temperature changes, divides into two nearly equal branches to operate the two instruments. Solar heating in the one is compensated by electrical heating in the other, interchanging the two instruments at intervals of two minutes. The measurement consists only in adjusting and observing the required electric current to exactly compensate the solar heating, so that the two water currents issue at exactly equal temperatures. Equality of their temperatures is indicated by eight thermoelectric elements connected in series with their junctions alternately immersed in the two issuing water currents.

This instrument, called water-flow pyrheliometer No. 5, was finished in May, 1932. Immediately afterwards Messrs. Aldrich and Kramer constructed a doubly dispersing spectroscope designed to observe the extreme infra-red solar spectrum between wave lengths 10 and 30 microns. This is the spectral region wherein the earth emits radiation most strongly. As the sun rays come through the atmosphere much as the earth rays pass out through it, the instrument was intended to measure accurately the transmission of the atmosphere to earth rays, a subject fundamental to meteorology.

A large diffraction grating of 25 lines per millimeter was very kindly ruled for this instrument by Dr. H. D. Babcock, of the Mount Wilson Observatory, by cooperation of Director W. S. Adams. A potassium-iodide prism for the second dispersion was kindly loaned by the University of Michigan. The instrument was completed about June 1, 1932, and shipped to Mount Wilson, Calif.

Mrs. A. M. Bond and Doctor Abbot did a great deal of work on the investigation of periodicities in solar and terrestrial phenomena by the aid of the periodometer, referred to in last year's report. Several papers descriptive of this work will be found in Smithsonian Miscellaneous Collections, volume 85, No. 1, and volume 87, Nos. 4 and 9.

FIELD WORK AT MOUNT WILSON

Messrs. Abbot and Aldrich left Washington about June 4, 1932, to conduct experiments on Mount Wilson. They obtained excellent comparisons between water-flow pyrheliometer No. 5 and silver-disk pyrheliometer S. I. 5_{bis} during June. These results, it is believed, fix the standard scale of solar radiation to within 0.2 per cent. The expedition was continued through the summer. Its results will be described in next year's report.

FIELD WORK AT MONTEZUMA, CHILE, AND TABLE MOUNTAIN, CALIF.

Daily observations of the solar constant of radiation were continued at the two permanent field stations. Unfortunately a great volcanic eruption in southern Chile rendered the atmosphere at Montezuma very hazy. This has prevented obtaining satisfactory measurements of the solar constant since April, 1932, and the daily reports to the United States Weather Bureau and to Science Service were therefore discontinued.

A. F. MOORE'S EXPEDITION

As stated in last year's report, Mr. and Mrs. A. F. Moore have been engaged in testing the availability of certain high mountains in Africa as solar-constant stations. Their observations at Fogo in the Cape Verde Islands and on some half dozen peaks in Southwest

Africa revealed nothing sufficiently favorable. All of these stations were too much affected by high-lying haze in the atmosphere to be satisfactory. From Southwest Africa Mr. and Mrs. Moore went to Mount St. Katherine, in the Sinai Peninsula in Egypt. With the good will and much aid from the archbishop and monks of the monastery near by, Mr. and Mrs. Moore carried on observations for about 100 days in April, May, June, and July, 1932, at the peak, whose elevation is about 8,600 feet. The results are the most favorable they found anywhere. About half the days are reported as excellent or satisfactory, the remainder as hazy or cloudy. Inquiries indicate that the other parts of the year will be still more favorable. Mr. Moore believes that many of the hazy days might have yielded good solar-constant values, for the haze changes but slowly, owing to the extraordinarily calm conditions which prevail on Mount St. Katherine continually.

PERSONNEL

At Washington, in compliance with the President's wishes to make all possible curtailment of expenditures in view of the growing deficit in the Treasury, the force was reduced by releasing Mrs. Muriel D. Johnson, computer, after the completion of Volume V of the Annals. L. O. Sordahl, formerly in charge of the Mount Brukkaros station and who had rendered able service in that connection, was released because of the discontinuance of that observatory as of June 30, 1932. No other changes occurred at any of the stations.

SUMMARY

Volume V of the Annals of the Observatory, covering work of the years 1920-1930, has been published. New instruments and results bearing on standards of pyrheliometry have been completed. Solar-constant work was discontinued in Southwest Africa, but continued at the Californian and Chilean stations. The volcanic eruption in southern Chile led to a temporary suspension of publication of daily solar-constant values. Much work was done with the periodometer, a special instrument devised to discover and evaluate periodicities in long series of observations. Mr. and Mrs. Moore continued an expedition in Africa to discover a suitable mountain site for a solar-constant observatory. The most favorable site discovered is Mount St. Katherine in the Sinai Peninsula in Egypt.

C. G. ABBOT, *Director.*

The SECRETARY,
Smithsonian Institution.

APPENDIX 8

REPORT ON THE DIVISION OF RADIATION AND ORGANISMS

SIR: I have the honor to submit the following report on the activities of the Division of Radiation and Organisms during its third year, ending June 30, 1932:

FACILITIES, SUPPORT, AND OPERATIONS

This division occupies as laboratories a large part of the basement of the original Smithsonian Building, extending from about the northern line of the towers westward but not including the space under the chapel. Besides these quarters, it occupies offices in the north tower from the fifth to the eleventh stories.

The work of the division is supported in part by the income of the Smithsonian endowment, but largely by annual grants from the Research Corporation of New York, to whom our sincere thanks are due. Besides this aid, cooperative relations exist with the United States Department of Agriculture, and through Doctor Meier, a fellow, with the National Research Council. Several commercial concerns, including the Corning Glass Works, the Bausch & Lomb Optical Co., the Westinghouse Electric Co., and the General Electric Co., have been very helpful.

The chief emphasis during the past year has been upon actual experimental work in biophysics. A number of the experiments which were reported as in progress at the end of 1931 have been carried to successful completion, with interesting results. Whereas the first year was largely devoted to building and equipping a laboratory in the basement of the Smithsonian Institution and the second year to the development of special apparatus for the unusual type of research to be undertaken, the past year has found these undertakings progressed to such a degree that efficient experimental work was possible. Initial experiments have been carried out which lay the foundation for continued investigations which we believe will prove valuable.

PHOTOSYNTHESIS

The carbon dioxide assimilated by wheat has been measured for light intensities varying from 78 to 1,900 foot-candles and for carbon-dioxide concentrations varying from 0.004 to 0.500 per cent. The

wheat is grown in an all-vitreous tubular container illuminated symmetrically from four sides. The wheat is protected by a sheet of copper-sulphate solution which serves the double purpose of maintaining the temperature and absorbing the excessive infra-red from the artificial sources. Carbon-dioxide concentration was measured by means of a potassium-hydroxide conductivity cell. The chief difficulties in this type of measurement have arisen from the high temperature coefficient and the polarization of the conductivity cell. These have been overcome, respectively, by improved thermostating

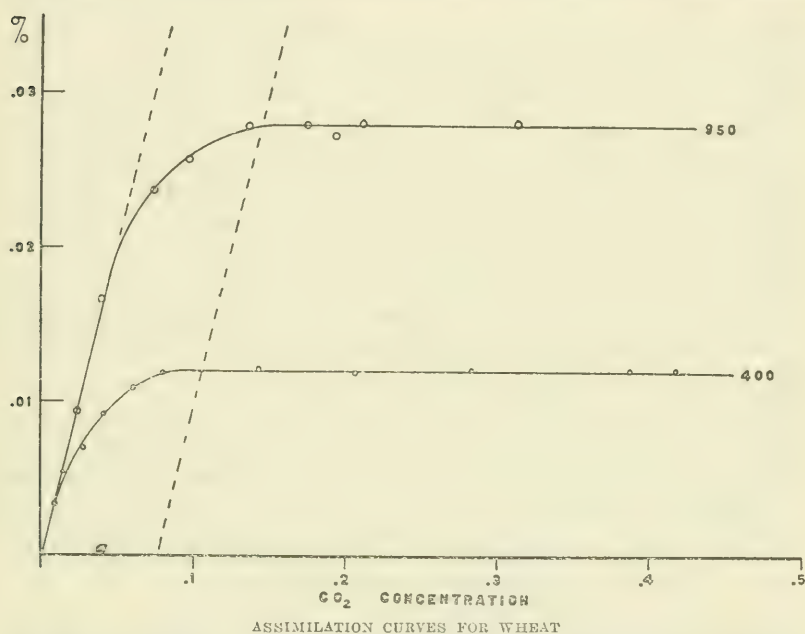


FIGURE 1.—Assimilation as a function of concentration for light intensities 400 foot-candles and 950 foot-candles

which holds the solutions to within less than one one-hundredth of a degree, and the installation of a commutator which reverses the polarity of the conductivity cell without changing the direction of the current through the galvanometer. By this method it has been possible to secure carbon-dioxide measurements which are significant to the order of one one-thousandth of a per cent. Typical curves of assimilation as a function of carbon-dioxide concentration are shown in Figure 1. Each of these curves represents the values for a single light intensity. For a light intensity of 950 foot-candles photosynthesis is proportional to the concentration of carbon dioxide from 0 to 0.04 per cent. A maximum rate is reached at a concentration of 0.140 per cent. Further increase in concentration up to one-half per cent produces no further change in assimilation, light intensity

being the limiting factor for this range. At a lower light intensity of 400 foot-candles departure from linear proportionality to concentration begins at a much lower value, of the order of 0.01 per cent, maximum being reached at approximately 0.10 per cent, after which no further change takes place in the range of experiment.

Referring to Figure 2 we see that for a carbon-dioxide concentration of 0.140 per cent the assimilation is proportional to the light intensity for the range from 0 to 1,000 foot-candles. On the other hand, for a concentration of 0.01 per cent a maximum is reached for

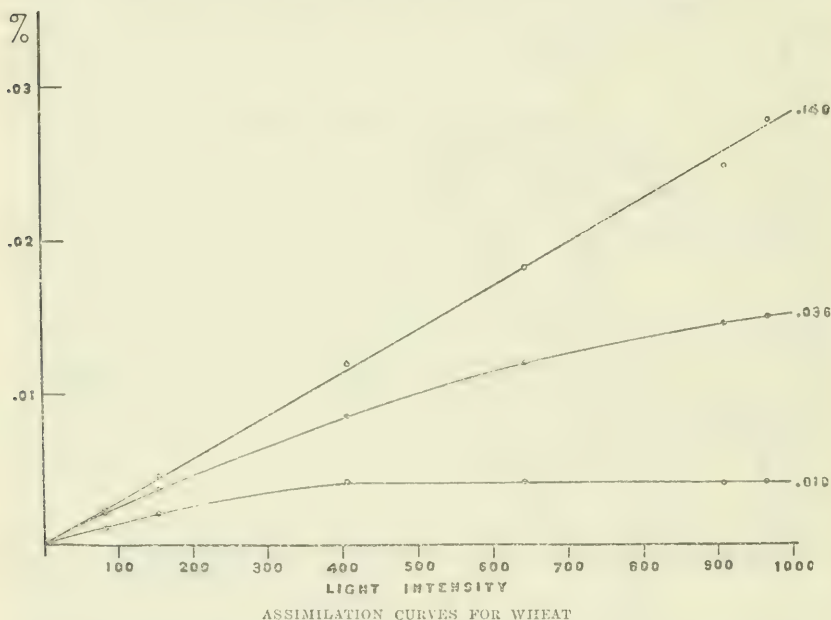


FIGURE 2.—Assimilation as a function of light intensity for carbon dioxide concentration 0.010, 0.036, 0.140 per cent

light intensity of 400 foot-candles, after which further increase in light intensity produces no change, carbon dioxide being the limiting factor. It thus appears that carbon dioxide may be the limiting factor for sufficiently high light intensities, assimilation varying proportionally to the carbon-dioxide concentration over a considerable range. On the other hand, for sufficiently high carbon-dioxide concentrations the light intensity may become the limiting factor, assimilation being proportional to the light intensity. There exist, however, well-defined regions over which the assimilation is dependent upon both factors. In examining the significance of this transition range, however, it must be borne in mind that ideal conditions can not be secured. Not all the chloroplasts can be maintained in the same radiation density, nor can exactly the same con-

centration of carbon dioxide be brought in contact with all the surfaces of the leaves. Nevertheless, the apparatus has been so designed as to minimize these difficulties. The fact that the sources of radiation are symmetrically placed on all four sides not only reduces the fluctuations of intensity as a function of direction, but, owing to the fact that the leaves are exposed from both sides, reduces to a minimum the variation of intensity through the leaf. A method of recirculation reduces the variation of concentration over the plant to about one-thirtieth part of the difference between the input and the output concentrations.

In view of these precautions it does not seem likely that the whole of this transition range can be accounted for by variations in the environment. It is beyond the scope of this report to enter upon a more critical and detailed discussion of these points and the wide literature bearing upon them. A number of considerations are of particular interest: First, that for an intensity of approximately one-tenth of maximum sunlight the carbon-dioxide concentration of air is the limiting factor. As one goes to lower light intensities, intensity becomes first partially limiting and then wholly limiting, so far as the actual conditions controlling the growth of higher plants are concerned. On the other hand, by the extrapolation of the linear portion of this curve for the range where carbon dioxide is the limiting factor, together with the addition of the value a for the transition range, one may arrive at the concentration of carbon dioxide which would be required to give a maximum assimilation for available light intensity. Assuming for such a noonday intensity $7 \times$ our experimental condition of 950 foot-candles one obtains

$$7 \times 0.069 + 0.081 = 0.564 \text{ per cent.}$$

Such an increase in available carbon dioxide would yield an increased assimilation rate amounting at times to tenfold or more.

This experiment has been chiefly conducted by Mr. Hoover. Doctor Johnston has worked with him upon some of the physiological phases, and Doctor McAlister upon the light-intensity measurements.

PLANT GROWTH

A set of individual plant-growth chambers has been completed which enables one to make comparative observations upon the effects of different wave length distributions of light. The four chambers have been so constructed as to permit of both lateral and overhead illumination. They are controlled by a central circulating system which maintains the same temperature and humidity in the four chambers. Rate of recirculation is maintained constant by flow meters. The same nutrient solution is used throughout. With

this complete control of environment one can be assured of the significance of growth effects arising from modifications in light conditions alone.

A first experiment has been conducted by Doctor Johnston with this equipment, which indicates that an excessive intensity in the less refrangible end of the spectrum, that is, the infra-red and extreme red, is accountable for much of the abnormal appearance of plants grown in artificial light. Further experiments will be conducted which will indicate to what degree the long wave length end of the spectrum should be excluded. In the present experiment a portion of the red as well as the infra-red was cut off. Very likely this will not be necessary.

A set of color filters of unusually great diameter has been obtained through the cooperation of the Corning Glass Works. These present interesting possibilities for the investigation of the effects of light upon plant growth. Figure 3 shows the transmission char-

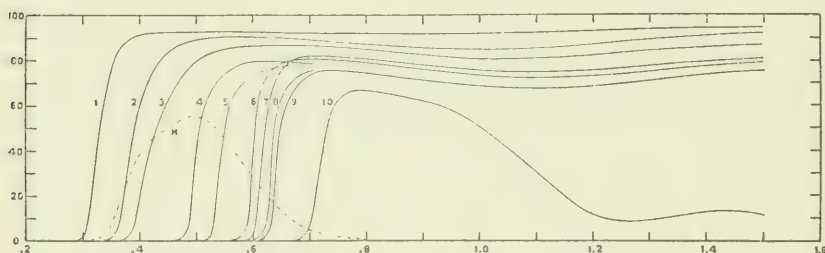


FIGURE 3.—Transmission curves of growth chamber filters

acteristics which we have obtained from these filters. In this diagram transmission in per cent is plotted against wave length in microns. This group offers an opportunity to study the effects of different portions of the visible light, since the range of wave lengths which may be supplied to the plants can be varied in convenient steps. The effects of photochemical reactions which may proceed only for wave lengths shorter than some specified value may be observed from the growth of plants under these various filters.

ALGAE

Dr. Florence Meier, National Research fellow, cooperating with Doctor McAlister of our laboratory, has conducted an interesting set of experiments on the lethal effects of the ultra-violet upon unicellular algae. This work has been made possible through the completion of a special combined spectrometer and self-recording monochromator. The instrument is of unusually great aperture as well as dispersive power. Two fused quartz prisms some 15 cm high, yield a large spread of the spectrum, which makes it possible to work with the relatively large slit widths required by the necessarily

coarse-structured biological plates which are prepared by forming a surface inoculation of algae upon agar. A special plate holder has been constructed which can be thoroughly sterilized in an autoclave, and which completely surrounds the algal plate even during exposure, thus insuring freedom from contamination. A thermocouple is driven across the spectrum and automatically records the

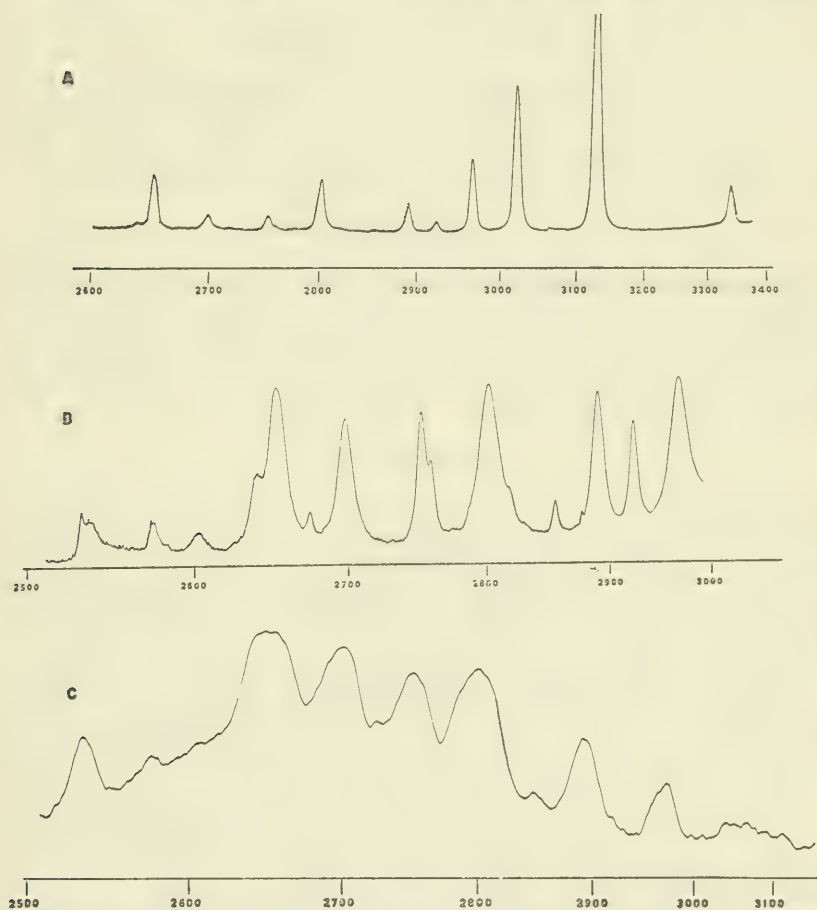


FIGURE 4.—Mercury arc spectrograms: A, direct thermocouple record; B, microphotometer record of photograph; C, microphotometer record of algal plate

intensities of the lines under the same conditions as those to which the algae have been exposed. The algal plates are then photographed and a densitometer record made just as one would with an ordinary photographic spectrum.

Figure 4 shows, first, the direct thermocouple record obtained automatically, curve A; second, the microphotometric record of a photographic spectrogram of the same general region, curve B; and third, such a microphotometric record of the algal plate, curve C.

PHOTOTROPISM

Phototropic investigations previously reported have been carried further into the blue end of the spectrum. It has been found that a maximum is reached at 4,500 Å., the phototropic response dropping off rapidly then as one proceeds to 4,000 Å. The results of the investigation at this stage were reported by Doctor Johnston to the American Society of Plant Physiologists at New Orleans in December of this year. Later experiments have indicated that departures from a simple curve, rising to a maximum and falling off again, are present. Further research is being carried on in order to determine whether fine structure may be present which would have an interesting bearing upon the theory of phototropism.

ULTRA-VIOLET

Ultra-violet measurements of the mercury arc with the double monochromator previously reported have been carried to the point where absolute intensities can be determined with reasonable certainty. The results of this investigation are in the process of publication by Doctor McAlister.

COOPERATION

Cooperative work with the Department of Agriculture has been greatly advanced by the appointment to their staff in the Bureau of Plant Industry, under Dr. Walter T. Swingle, of Dr. Lauriston C. Marshall. Doctor Marshall is working closely with this division upon their problems in determining the effects of radiation upon non-competitive crop plants. Doctor Marshall is a physicist with special qualifications in the fields of photoelectricity and electrical conductivity through gases. The division has profited greatly by his association, as his experience supplements that of the physicists of the division, whose line of work has been chiefly in spectroscopic fields.

Continued cooperation with the Fixed Nitrogen Research Laboratory has made possible convenient exchange of facilities. Arrangements have been made with the Westinghouse Laboratories for the exchange of thermocouples and photocells, which will greatly facilitate our ultra-violet work.

Respectfully submitted.

F. S. BRACKETT, *Chief*

Dr. C. G. ABBOT,

Secretary, Smithsonian Institution.

APPENDIX 9

REPORT ON THE INTERNATIONAL CATALOGUE OF SCIENTIFIC LITERATURE

SIR: I have the honor to submit the following report on the operations of the United States Regional Bureau of the International Catalogue of Scientific Literature for the fiscal year ending June 30, 1932:

In addition to the regular routine work of the bureau, direct correspondence with the former regional bureaus has been carried on in an attempt to resume the actual publication of this unique reference catalogue, whose absence is keenly felt alike by students of science and librarians. To this end the Secretary of the Smithsonian Institution addressed the following letter to 30 of the various bodies formerly cooperating in the work:

JANUARY 15, 1932.

DEAR SIR: Since publication of the International Catalogue of Scientific Literature was discontinued, its need both to students of science and libraries has become ever more pressing, and the Smithsonian Institution desires to do everything possible to promote reorganization of the enterprise. I am writing to ask whether your institution will again cooperate in the work by supplying classified references to the current scientific literature of your region if a sufficient capital fund can be provided to reestablish and finance the central bureau. If publication is to be resumed, aid from the regional bureaus formerly cooperating is essential to success; therefore I trust that your reply will be favorable, as it is obvious that the value of the work will depend on all regions being suitably represented.

I am inclosing with this a brief outline of the proposed organization plans, together with copies of three annual reports of this bureau containing matter relating to same subject.

Very truly yours,

(Signed) C. G. ABBOT, *Secretary.*

PROPOSED REORGANIZATION OF THE INTERNATIONAL CATALOGUE OF SCIENTIFIC LITERATURE

In 1922 the International Catalogue of Scientific Literature in convention at Brussels directed its executive committee to submit a plan for reorganization when international conditions had sufficiently improved. Since then, however, international political and financial conditions have been such that no reorganization plan has been forthcoming. The need for the catalogue is to-day greater than when publication ceased and nothing has appeared to take its place.

The organization, consisting of some 34 regional bureaus, cooperating through the Central Bureau in London, supplied classified-index references for the catalogue, and this method appears to have been ideal in accomplishing this the

most difficult phase of the work. Moved by the fixed desire to see this great work resumed, the Smithsonian Institution is now addressing the bodies formerly cooperating requesting assurances of renewed aid by supplying classified indexes to the scientific literature of their respective regions. The Institution has figures showing that a catalogue consisting of 10,000 pages, divided into 17 annual volumes, can be published to sell at a cost of \$50 per year, provided 1,000 subscriptions can be had.

The situation is now far simpler than it was when the organization was founded in 1900, for then no precedent existed for such an international co-operative enterprise. Now the successful publication of 238 volumes aggregating some 140,000 pages of the International Catalogue is substantial and convincing proof that the original plan was feasible. War and disorganized international conditions alone were responsible for the necessity of suspending publication. Faults existed, but faults mainly brought about by lack of capital and a somewhat slow and expensive method of printing through private concerns. It is now proposed to remedy these defects through the ownership of a specially designed and equipped plant to print only the International Catalogue. By this means it is believed that the catalogue can be printed for approximately one-half the original cost and the two main defects formerly existing—high prices and delayed publication—be remedied.

It is apparent that in the proposed reorganization it is first necessary to obtain assurance from regional bureaus that the aid formerly given can be depended on again to supply classified references, as in this cooperation lay the outstanding and unique value of the whole project.

When such assurance is received the next step will be to solicit subscriptions to determine whether editions of 1,000 sets of 17 annual volumes can be sold in order to reduce the price to \$50 per set.

With these essential requirements satisfactorily met and a concise plan of operations agreed to, it is hoped and expected that the necessary capital to resume publication, estimated at \$75,000, can be obtained.

Operating details may well be based on the records and regulations of the organization as formerly carried out by the London Central Bureau.

Responses to these communications have been most gratifying and encouraging, as 16 of the 18 replies received from organizations addressed have agreed to cooperate again on the terms outlined. For various reasons, owing to social and political changes resulting from the war, successful contacts have not been made in a number of regions; but it is believed that when a definite plan has been agreed to among the bodies already cooperating, all regional gaps can be filled, as the importance of the work is so well recognized that no country or region could afford to be omitted.

Respectfully submitted.

LEONARD C. GUNNELL,
Assistant in Charge.

Dr. CHARLES G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 10

REPORT ON THE LIBRARY

SIR: I have the honor to submit the following report on the activities of the Smithsonian library for the fiscal year ended June 30, 1932:

THE LIBRARY

The library of the Smithsonian Institution is really a library system, for it comprises 45 distinct libraries, namely, the Smithsonian deposit in the Library of Congress, office library, Langley aeronautical library, radiation and organisms library, the libraries of the United States National Museum, Bureau of American Ethnology, Astrophysical Observatory, National Gallery of Art, Freer Gallery of Art, National Zoological Park, and the 35 sectional libraries of the National Museum, which are the daily tools of the curators and their assistants. The system contains somewhat more than 800,000 volumes, pamphlets, and charts, as well as many thousands of items still uncatalogued or awaiting completion.

THE STAFF

At the close of the calendar year Miss Kate Gallaher, under library assistant, after more than 50 years of faithful Government service, most of it in the Smithsonian library, was retired, and her place was filled by the promotion of Miss Virginia C. Whitney, minor library assistant. To the vacancy thus occasioned was appointed Bruce Middleton, a graduate of the University of Rochester, who had had several years of library and clerical experience in the Rochester public library and the United States Census Bureau. The services of Mrs. Grace A. Parler, in the library of the Freer Gallery of Art, were continued. The other temporary employees were Mrs. Daisy Cadle, Miss Frances Finch, Miss Alice Elizabeth Hill, Miss Margaret Link, and Miss Jennette Seiler.

EXCHANGE OF PUBLICATIONS

In the course of the last year the library received 24,651 packages of one or more publications each, most of them exchanges. Especially large sendings came from the Audubon Association of the Pacific, San Francisco; Gesellschaft für Erdkunde, Leipzig; Hiroshima University, Hiroshima; Institut d'Estudis Catalans, Barcelona; Landesmuseums-verein für Vorarlberg, Bregenz; Lingnan

University, Canton; Magyar Aero Szövetseg, Budapest; Royal Anthropological Institute of Great Britain and Ireland, London; R. Università, Pavia; and Saalburgmuseum, Homburg vor der Höhe. Among the publications received were 5,340 dissertations, chiefly from foreign universities and technical schools.

The correspondence of the library, involving 2,836 letters, or 1,028 more than the previous year, had to do largely, as usual, with the exchange of publications. The number of items obtained to meet special needs in various libraries of the Institution was 4,133, or 543 more than in 1931, the greatest increase being shown in those received for the library of the National Museum, where a special effort was made to check the standard sets.

GIFTS

Three gifts were outstanding—namely, a set, in 45 volumes, of the Phra Tripitaka, recently translated from the Bali into Siamese by the Mahamongkut Academy, from His Majesty the King of Siam in honor of His Majesty the late King Phra Mongkut Klao and for the encouragement of orientalists in their studies of the eastern classics; a set, in 3 volumes, of the translation into Siamese of the Paramatthamanjusa Visuddhi Maggatika (Commentaries on the Visuddhi-Magga), from His Excellency Chao Phya Abbai Raja; and a copy of Cristoforo Colombo—Documenti & prove della sua appartenenza a Genova, presented by His Excellency Dino Grandi during his recent visit to Washington as Royal Italian Minister of Foreign Affairs. Two other very important gifts were a copy, in 3 volumes, of Mohenjo-Daro and the Indus Civilization, edited by Sir John Marshall, from the editor, and one of volumes 19 and 20, with portfolios of plates, of The North American Indian, by Edward S. Curtis, from Mrs. E. H. Harriman—to complete the Smithsonian set of this superb work. Still other gifts included the following: Birds of Tropical West Africa, volume 2, by David Armitage Bannerman, from the Crown Agents for the Colonies; The Crosses and Culture of Ireland, by A. Kingsley Porter, from the Metropolitan Museum of Art; Faraday and His Metallurgical Researches, by Sir Robert A. Hadfield, from Maj. Gen. George O. Squier; Illustrated Catalogues of the Gustave Dreyfus Collection (Reliefs and Plaquettes, Medals, Bronzes), 3 volumes, from Sir Joseph Duveen; Illustrations of Japanese Aquatic Plants and Animals, 2 volumes, by the Fisheries Society of Japan, from the society; An Introduction to the Literature of Vertebrate Zoology, edited by Casey A. Wood, from the Blacker Library of Zoölogy, McGill University; Les Oiseaux de l'Indochine Française, by J. Delacour and P. Jabouille, from J. Delacour; and Problems in Modern Physics, by H. A. Lorentz, from

Robert A. Millikan. The largest miscellaneous gifts were 31 publications from Miss Margaret Miller, 37 from Dr. Adam G. Böving, 58 from the American Association of Museums, 70 from Mrs. Jean L. G. Ferris, 144 from the Library of Congress, 454 from Hamilton College, 615 from William Perry Hay, and 650 from the American Association for the Advancement of Science. Several hundred also came, as usual, from Mrs. Charles D. Walcott.

The members and associates of the Institution who gave publications to the library were as follows: Secretary Abbot, Assistant Secretary Wetmore, Dr. R. S. Bassler, Dr. Marcus Benjamin, A. N. Caudell, A. H. Clark, W. L. Corbin, Dr. Herbert Friedmann, Miss Kate Gallaher, A. H. Howell, Dr. Aleš Hrdlička, Neil M. Judd, Dr. W. R. Maxon, G. S. Miller, jr., C. W. Mitman, A. J. Olmsted, W. de C. Ravenel, J. H. Riley, and Dr. William Schaus. From the late Dr. Charles W. Richmond also were received 100 or more volumes and pamphlets, not a few of which were rare works on natural history.

THE SMITHSONIAN DEPOSIT

The Smithsonian deposit in the Library of Congress is the largest and most important member of the Smithsonian library system; it consists chiefly of the reports, transactions, and proceedings of learned societies and institutions, and of scientific and technical monographs and journals. The collection numbers considerably more than 500,000 volumes, pamphlets, and charts. It is shelved mainly in the Smithsonian and periodical divisions. During the year just closed the Institution added to the deposit 2,872 volumes, 11,712 parts of volumes, 2,883 pamphlets, and 180 charts—a total of 17,647 publications. These included 3,436 dissertations. They also included 2,445 publications which the Smithsonian library obtained by exchange in response to special requests from the Smithsonian, periodical, and order divisions of the Library of Congress. Several thousand documents of foreign governments were sent to the documents division of the Library.

NATIONAL MUSEUM LIBRARY

The library of the United States National Museum is one of the principal units in the Smithsonian library system. In its 2 major and 35 minor collections—chiefly on natural history and technology—there are 82,144 volumes and 109,962 pamphlets. The year just closed was one of unusual accomplishment. The accessions were 2,737 volumes and 833 pamphlets, a gain of 210 over the previous year. The number of periodicals entered was 9,025, or 226 more than in 1931. The cataloguing and recataloguing covered 2,236 volumes, 1,006 pamphlets, and 17 charts—an increase of 818 over the year

before. The number of cards added to the catalogue was 12,055, or 862 more than in 1931; the number added to the Museum shelf lists, 1,244; and the number prepared for the union shelf list in the Smithsonian Building, 1,741. The items sent to the 35 sectional libraries numbered 5,726 volumes and parts. The number of volumes sent to the bindery was 1,480. The Smithsonian library obtained in exchange for the Museum 1,377 volumes and parts that were lacking in its sets, 287 more than in 1931. The loans during the year to the staff of the Smithsonian Institution and its branches totaled 9,096 publications, or 1,875 more than in 1931. Two-thirds of these were made at the loan desk in the Natural History Building and one-third at the recently established loan desk in the Arts and Industries Building. The number of publications borrowed from the Library of Congress was 2,662, and elsewhere 477; the number sent back to the Library of Congress was 2,800, and to other libraries 532. These figures show a considerable increase over those for 1931. Loans were made to many libraries in Washington and to some outside. The questions answered by the reference assistants were even more numerous and difficult than usual, some involving a great deal of research. Most came from the scientific staff and the public in general, but many from visiting scientists from various parts of the country. Increased attention was given by the catalogue division to the analysis of standard sets, with a view to making the catalogue as complete a key as possible to these publications.

The sectional libraries were somewhat changed during the year. Those of mechanical technology and mineral technology became that of engineering, those of American archeology and Old World archeology that of archeology, and a sectional library of agricultural history was begun. These libraries, now 35 in number, are as follows:

Administration.	Invertebrate paleontology.
Administrative assistant's office.	Mammals.
Agricultural history.	Marine invertebrates.
Anthropology.	Medicine.
Archeology.	Minerals.
Biology.	Mollusks.
Birds.	Organic chemistry.
Botany.	Paleobotany.
Echinoderms.	Photography.
Editor's office.	Physical anthropology.
Engineering.	Property clerk's office.
Ethnology.	Reptiles and batrachians.
Fishes.	Superintendent's office.
Foods.	Taxidermy.
Geology.	Textiles.
Graphic arts.	Vertebrate paleontology.
History.	Wood technology.
Insects.	

OFFICE LIBRARY

The office library consists mainly of books of reference and sets of the publications of the Institution and its bureaus and of other learned institutions and societies. It also contains a collection of general literature, including files of semipopular magazines. To this library were added during the last year 132 volumes and 47 pamphlets. The assistants in charge entered 2,889 periodicals, prepared 477 cards for the catalogue, filed 1,938 shelf-list and catalogue cards, and loaned 3,070 publications. Besides members of the staff, there were 644 visitors, many of whom came for information about the activities and collections of the Institution.

BUREAU OF AMERICAN ETHNOLOGY LIBRARY

The library of the Bureau of American Ethnology is made up largely of works on the archeology, history, customs, languages, and general culture of the early American peoples, notably the North American Indian. The library has 30,071 volumes and 16,867 pamphlets, together with thousands of unbound periodicals and numerous photographs, manuscripts, and Indian vocabularies. The additions during the year were 400 volumes and 150 pamphlets. The number of periodicals entered was 3,400; of cards prepared for the catalogue, 5,004; of volumes bound, 200; and of loans made, 2,156. The reference service of the library was unusually large, both to Smithsonian scientists and to students and others outside the Institution.

ASTROPHYSICAL OBSERVATORY LIBRARY

The library of the Astrophysical Observatory is a working collection of 4,357 volumes and 3,467 pamphlets, chiefly on astrophysics and meteorology. The accessions for the year were 169 volumes and 275 pamphlets. The number of periodicals entered was 951, and of publications obtained in exchange by special request 84. The loans were 106.

RADIATION AND ORGANISMS LIBRARY

The library of radiation and organisms, begun in 1929, was increased during the year by 96 volumes. Among these was almost a complete set of *Science*, which was made up largely from duplicates already in the possession of the Institution. The number of publications received in exchange in response to special requests was 43. The periodicals entered were 658. The library now has 190 volumes, 9 pamphlets, and 6 charts.

LANGLEY AERONAUTICAL LIBRARY

The Langley aeronautical library, which for the most part has been on deposit since 1930, under its own name and bookplate, in

the aeronautical division of the Library of Congress, was collected chiefly by Secretary Langley of the Smithsonian while he was carrying on his well-known experiments and researches in aeronautics. Some of the more important items were once the property of other aeronautical pioneers, especially Alexander Graham Bell, Octave Chanute, and James Means. The collection has files of the early aeronautical magazines and many photographs, letters, and newspaper clippings. It numbers 1,908 volumes and 1,086 pamphlets. The library was increased during the year by 52 volumes, 623 parts of volumes, and 30 pamphlets.

NATIONAL GALLERY OF ART LIBRARY

The library of the National Gallery of Art is a carefully selected collection of 1,334 volumes and 1,416 pamphlets, mainly on American and European art. In 1932 it was increased by 91 volumes and 84 pamphlets. Among the accessions were *Enciclopedia Italiana*, Volumes I-XIII; *Die Propyläen-kunstgeschichte*, Volumes I-XV; and *Life Portraits of George Washington*, by John Hill Morgan and Mantle Fielding. The periodicals entered were 387. As usual, most of the routine work was done by the general library staff.

FREER GALLERY OF ART LIBRARY

The library of the Freer Gallery of Art consists chiefly of publications on the arts and cultures of the Far East, India, Persia, and the nearer East. Many of these, some of which are very rare, are not to be found elsewhere in Washington. The collection also has numerous works on some of the American painters, notably James McNeill Whistler, and on the famous Washington manuscripts of the Bible. The additions to the main collection during 1932 were 254 volumes and 163 pamphlets. At the close of the year it numbered 4,677 volumes and 3,311 pamphlets, while the special collection used by the field staff in connection with the gallery's archeological work contained approximately 800 volumes and 500 pamphlets. The number of volumes bound was 21. The work of reclassifying and recataloguing the library was completed, except for various publications in Japanese and Chinese. The catalogue and shelf list were increased by 3,507 cards, and 2,666 cards were prepared for filing in the union catalogue at the Smithsonian Institution.

NATIONAL ZOOLOGICAL PARK LIBRARY

The library of the National Zoological Park numbers 1,221 volumes and 410 pamphlets; the additions in 1932 were 4 volumes and 3 pamphlets.

SUMMARY OF ACCESSIONS

The accessions for the year may be summarized as follows:

Library	Volumes	Pamphlets and charts	Total
Astrophysical Observatory.....	169	275	444
Bureau of American Ethnology.....	400	150	550
Freer Gallery of Art.....	254	163	417
Langley aeronautical.....	52	30	82
National Gallery of Art.....	91	84	175
National Zoological Park.....	4	3	7
Radiation and Organisms.....	96	0	96
Smithsonian deposit, Library of Congress.....	2,872	3,063	5,935
Smithsonian office.....	132	47	179
United States National Museum.....	2,737	833	3,570
Total.....	6,807	4,618	11,455

On June 30, 1932, the Smithsonian library system contained approximately the following:

Volumes.....	584,864
Pamphlets.....	196,945
Charts.....	26,526
Total.....	808,335

The system also had many thousands of volumes still uncatalogued or incomplete.

UNION CATALOGUE

In addition to cataloguing the current items as they came in, the staff made considerable progress in recataloguing the botanical collection of the National Museum, and almost finished the reclassifying and recataloguing of the library of the Freer Gallery of Art.

The following statistics will show the work on the union catalogue and shelf list:

Volumes catalogued.....	4,922
Volumes recatalogued.....	13
Pamphlets catalogued.....	2,733
Pamphlets recatalogued.....	3
Charts catalogued.....	197
Typed cards added to catalogue and shelf list.....	9,848
Library of Congress cards added to catalogue and shelf list.....	13,208
Museum cards copied for union shelf list.....	1,741
Freer cards prepared for union catalogue and shelf list, to be added later.....	2,666

SPECIAL ACTIVITIES

Still further progress was made during the year in putting the scientific duplicates in the west stacks in order. The shelves of the botanical library were completely rearranged. About 50 sacks of the publications of the Institution and its branches, which had been

returned as duplicates from various libraries throughout the country, were opened and their items examined and grouped. As a result, thousands of publications were sent back to stock for redistribution, and nearly 250 that were out of print were found for the sets that the library system has been trying for many years to complete. Duplicates were exchanged with several institutions, and many publications not needed by the Smithsonian or its bureaus were turned over to other Government libraries.

The librarian lectured several times in Washington and Baltimore on Washington the Man of Books and Patron of American Letters. In the course of his remarks he called attention to two matters of especial interest to the Smithsonian Institution. One was the gift of a set of *Histoire Generale des Voyages*, in 20 volumes, from the Marquis de Rochambeau to Washington, which on its way to the United States was captured on the high seas by a British cruiser and taken to England. It was later found in a London book shop by Prof. George Brown Goode, then Assistant Secretary of the Institution, brought to America, and presented to Mount Vernon, where it now reposes in Washington's library. The other was a letter that Washington wrote to Jonathan Edwards on August 28, 1788, thanking him for a copy of his recent book entitled "Observations on the Language of the Muhhekaneew Indians." In this letter Washington said: "I have long regretted that so many Tribes of the American Aborigines should have become almost or entirely extinct, without leaving such vestiges, as that the genius and idiom of their language might be traced. Perhaps, from such sources, the descent or kindred of nations, whose origins are lost in remote antiquity or illiterate darkness, might be more rationally investigated, than in any other mode." Thus the many-sided Washington showed himself one of the first men in our country to realize the great importance of the preservation and study of the languages of the North American Indians as a means of tracing the history of these early people.

IMPORTANT BEGINNINGS

Toward the close of the year a beginning was made in reorganizing the order division of the library with a view to developing a more modern and efficient procedure and one more closely related to that in the other divisions. Plans were also worked out for making a file of the library's exchange relations, to the end of having immediately at hand for the use of the periodical division, especially the correspondence section, full data pertaining to the library's exchanges and of facilitating the more frequent revision of its exchange lists in keeping with the needs of stricter economy. And, perhaps most important of all, arrangements were completed for

preparing an index to the publications of the Smithsonian Institution, National Museum, Astrophysical Observatory, and Bureau of American Ethnology. This will be a dictionary index and will at first be on Library of Congress cards. Cards for all the publications, except volumes 1 to 36 of the Proceedings of the National Museum, are already available, and the Smithsonian library staff will soon set about supplying manuscript to the Library of Congress for the printing of cards for these volumes. It is hoped that if some day the Institution is in position to publish the index, the material for it will be ready. The need for such an index is, of course, apparent to everyone.

Respectfully submitted.

WILLIAM L. CORBIN, *Librarian*.

Dr. CHARLES G. ABBOT,

Secretary, Smithsonian Institution.

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APPENDIX 11

REPORT ON PUBLICATIONS

SIR: I have the honor to submit the following report on the publications of the Smithsonian Institution and the Government bureaus under its administrative charge during the year ending June 30, 1932:

As announced last year, the three editorial offices formerly existing under the Institution have been consolidated into one central office under the general direction of the editor of the Smithsonian. This arrangement has proved to be very satisfactory; it has produced a more uniform style and greater accuracy in the different series published by the Institution, has speeded up the appearance of the publications, and has centralized the business operations connected with the Institution's editorial work.

PUBLICATIONS ISSUED DURING THE YEAR

The Institution proper published during the year 17 papers in the series of Smithsonian Miscellaneous Collections, 1 annual report and pamphlet copies of the 29 articles contained in the report appendix, Volume V of the *Annals of the Astrophysical Observatory*, and 3 special publications. The United States National Museum issued 1 annual report, 2 volumes of proceedings, 5 complete bulletins, 3 parts of bulletins, 1 paper in the series *Contributions from the National Herbarium*, and 53 separates from the proceedings. The Bureau of American Ethnology published 7 bulletins.

The total number of publications distributed was 223,045 copies, which included 118 volumes and separates of the Smithsonian Contributions to Knowledge, 44,057 volumes and separates of the Smithsonian Miscellaneous Collections, 30,560 volumes and separates of the Smithsonian Annual Reports, 6,061 Smithsonian special publications, 101,975 volumes and separates of the various series of the National Museum publications, 22,867 publications of the Bureau of American Ethnology, 49 publications of the National Gallery of Art, 70 publications of the Freer Gallery of Art, 1,041 volumes of the *Annals of the Astrophysical Observatory*, 50 reports of the Harri-man Alaska Expedition, and 699 reports of the American Historical Association.

SMITHSONIAN MISCELLANEOUS COLLECTIONS

Of the Smithsonian Miscellaneous Collections, volume 82, 1 paper and title-page and table of contents were issued; volume 85, 8 papers and addendum to number 4; volume 86, whole volume; and volume 87, 7 papers, making 17 papers in all, as follows:

VOLUME 82

No. 11. Recently dated Pueblo ruins in Arizona, by Emil W. Haury and Lyndon L. Hargrave. 120 pp., 27 pls., 35 text figs. (Publ. 3069.) August 18, 1931.

Title-page and table of contents. (Publ. 3132.)

VOLUME 85

No. 4. Mexican mosses collected by Brother Arsène Brouard—III, by I. Thériot. 44 p., 22 text figs. (Publ. 3122.) August 25, 1931.

Addendum. Index to papers by I. Thériot on Mexican mosses collected by Brother Arsène Brouard published by the Smithsonian Institution.

No. 5. Infra-red absorption bands of hydrogen cyanide in gas and liquid, by F. S. Brackett and Uner Liddel. 8 pp., 5 figs. (Publ. 3123.) August 5, 1931.

No. 6. Morphology of the insect abdomen. Part I. General structure of the abdomen and its appendages, by R. E. Snodgrass. 128 pp., 46 text figs. (Publ. 3124.) November 6, 1931.

No. 7. Effectiveness in nature of the so-called protective adaptations in the animal kingdom, chiefly as illustrated by the food habits of Nearctic birds, by W. L. McAtee. 201 pp. (Publ. 3125.) March 15, 1932.

No. 8. Modern square grounds of the Creek Indians, by John R. Swanton. 46 pp., 5 pls., 15 text figs. (Publ. 3126.) November 11, 1931.

No. 9. The determination of ozone by spectrophotometric measurements, by Oliver R. Wulf. 12 pp., 3 pls., 5 text figs. (Publ. 3127.) November 30, 1931.

No. 10. Human hair and primate patterning, by Gerrit S. Miller, jr. 13 pp., 5 pls. (Publ. 3130.) December 19, 1931.

No. 11. Supplementary notes on body radiation, by L. B. Aldrich. 12 pp., 5 text figs. (Publ. 3133.) February 2, 1932.

VOLUME 86

(Whole volume.) Smithsonian Meteorological Tables. Fifth revised edition. 282 pp., 1 text fig. (Publ. 3116.) January 11, 1931.

VOLUME 87

No. 1. The botanical collections of William Lobb in Colombia, by Ellsworth P. Killip. 13 pp. (Publ. 3133.) February 4, 1932.

No. 2. A Miocene long-beaked porpoise from California, by Remington Kellogg. 11 pp., 4 pls. (Publ. 3135.) January 22, 1932.

No. 3. Seth Eastman: The master painter of the North American Indian, by David I. Bushnell, jr. 18 pp., 15 pls., 1 text fig. (Publ. 3136.) April 11, 1932.

No. 4. The periodometer: An instrument for finding and evaluating periodicities in long series of observations, by C. G. Abbot. 6 pp., 1 pl., 1 text fig. (Publ. 3138.) February 6, 1932.

No. 5. The narrative of a southern Cheyenne woman, by Truman Michelson. 13 pp. (Publ. 3140.) March 21, 1932.

No. 6. Composition of the Caddoan linguistic stock, by Alexander Lesser and Gene Weltfish. 15 pp. (Publ. 3141.) May 14, 1932.

No. 8. Graphic correlation of radiation and biological data, by F. S. Brackett. 7 pp. (Publ. 3170.) May 17, 1932.

No. 9. Periodicity in solar variation, by C. G. Abbot and Gladys T. Bond. 14 pp., 2 pls., 8 text figs. (Publ. 3172.) May 24, 1932.

SMITHSONIAN ANNUAL REPORT

Report for 1930.—The complete volume of the Annual Report of the Board of Regents for 1930 was received from the Public Printer in December, 1931.

Annual Report of the Board of Regents of the Smithsonian Institution showing the operations, expenditures, and condition of the Institution for the year ending June 30, 1930. xii+650 pp., 191 pls., 57 text figs. (Publ. 3077.)

The appendix contained the following papers:

Beyond the red in the spectrum, by H. D. Babcock.

Growth in our knowledge of the sun, by Charles E. St. John.

The modern sun cult, by J. W. Sturmer.

The moon and radioactivity, by V. S. Forbes.

Modern concepts in physics and their relation to chemistry, by Irving Langmuir.

Waves and corpuscles in modern physics, by Louis de Broglie.

New researches on the effect of light waves on the growth of plants, by F. S. Brackett and Earl S. Johnston.

The Autogiro: Its characteristics and accomplishments, by Harold F. Pitcairn.

Ten years' gliding and soaring in Germany, by Prof. Dr. Walter Georgii.

The first rains and their geological significance, by Assar Hadding.

Weather and glaciation, by Chester A. Reeds.

Wild life protection: An urgent problem, by Ernest P. Walker.

The nesting habits of Wagler's Oropendola on Barro Colorado Island, by Frank M. Chapman.

The rise of applied entomology in the United States, by L. O. Howard.

Man and insects, by L. O. Howard.

The use of fish poisons in South America, by Ellsworth P. Killip and Albert C. Smith.

A rare parasitic food plant of the Southwest, by Frank A. Thackery and M. French Gilman.

The mechanism of organic evolution, by Charles B. Davenport.

Extra chromosomes, a source of variations in the Jimson Weed, by Albert F. Blakeslee.

The age of the human race in the light of geology, by Stephen Richarz.

Elements of the culture of the circumpolar zone, by W. G. Bogoras.

The Tell en-Nasbeh Excavations of 1929—a preliminary report, by William Frederic Badé.

Recent progress in the field of Old World prehistory, by George Grant MacCurdy.

Ancient seating furniture in the collections of the United States National Museum, by Walter Hough.

Aspects of aboriginal decorative art in America based on specimens in the United States National Museum, by Herbert W. Krieger.

The acclimatization of the white race in the Tropics, by Robert De C. Ward.

The eighth wonder: The Holland Vehicular Tunnel, by Carl C. Gray and H. F. Hagen.

Jesse Walter Fewkes, by John R. Swanton and F. H. H. Roberts, jr.

George Perkins Merrill, by Charles Schuchert.

Report for 1931.—The report of the executive committee and proceedings of the Board of Regents of the Institution and the report of the Secretary, both forming parts of the annual report of the Board of Regents to Congress, were issued in December, 1931.

Report of the executive committee and proceedings of the Board of Regents of the Smithsonian Institution for the year ending June 30, 1931. 12 pp. (Publ. 3129.)

Report of the Secretary of the Smithsonian Institution for the year ending June 30, 1931. 159 pp., 2 pls., 9 text figs. (Publ. 3128.)

The Report volume, containing the general appendix, was in press at the close of the year.

ASTROPHYSICAL OBSERVATORY PUBLICATIONS

Annals of the Astrophysical Observatory, Vol. V, by C. G. Abbot, L. B. Aldrich, and F. E. Fowle. 295 pp., 9 pls., 33 text figs. (Publ. 3121.) April 20, 1932.

FREER GALLERY OF ART PUBLICATIONS

The Freer Gallery of Art. 5 pp. (Fourth printing.) August 6, 1932.

SPECIAL PUBLICATIONS

Explorations and field work of the Smithsonian Institution in 1931. 190 pp., 182 figs. (Publ. 3134.) April 21, 1932.

Handbook of the National Aircraft Collection exhibited in the United States National Museum under the direction of the Smithsonian Institution, by Paul Edward Garber. Fourth edition. 32 pp., 38 illustrations. (Publ. 3139.) April 5, 1932.

Smithsonian Mathematical Tables—Hyperbolic Functions. Prepared by George F. Becker and C. E. Van Orstrand. Fourth reprint. 321 pp. (Publ. 1871.) October 23, 1931.

PUBLICATIONS OF THE UNITED STATES NATIONAL MUSEUM

The editorial work of the National Museum has continued during the year under the immediate direction of the editor, Paul H. Oehser. There were issued 1 annual report, 2 volumes of proceedings, 5 complete bulletins, 3 parts of bulletins, 1 paper in the series Contributions from the National Herbarium, and 53 separates from the proceedings.

The issues of the bulletin were as follows:

Bulletin 100, vol. 2. Papers on collections gathered by the *Albatross* Philippine expedition, 1907–1910.

Bulletin 104. The Foraminifera of the Atlantic Ocean. Part 8. Rotaliidae, Amphisteginidae, Calcarinidae, Cymbaloporettidae, Globorotaliidae, Anomalinidae, Planorbulinidae, Rupertiidae, and Homotremidae, by Joseph Augustine Cushman.

Bulletin 156. Aboriginal Indian pottery of the Dominican Republic, by Herbert W. Krieger.

Bulletin 157. The butterflies of the District of Columbia and vicinity, by Austin H. Clark.

Bulletin 159. The birds of the Natuna Islands, by Harry C. Oberholser.

Bulletin 160. Mexican tailless amphibians in the United States National Museum, by Remington Kellogg.

Bulletin 161. The Foraminifera of the Tropical Pacific collections of the *Albatross*, 1899-1900. Part 1.—Astrorhizidae to Trochamminidae, by Joseph A. Cushman.

Bulletin 162. Life histories of North American Gallinaceous birds. Orders Galliformes and Columbiformes, by Arthur Cleveland Bent.

The following paper was issued in the series Contributions from the National Herbarium:

Volume 28, Part 2. The American species of Thibaudieae, by Albert C. Smith.

Of the separates from the proceedings, 28 were from volume 79, 21 from volume 80, and 4 from volume 81.

PUBLICATIONS OF THE BUREAU OF AMERICAN ETHNOLOGY

The editorial work of the bureau has continued under the immediate direction of the editor, Stanley Searles. During the year seven bulletins were issued, as follows:

Bulletin 94. Tobacco among the Karuk Indians of California (Harrington). xxxvi+284 pp., 36 pls., 2 figs.

Bulletin 98. Tales of the Cochiti Indians (Benedict). x+256 pp.

Bulletin 102. Menominee music (Densmore). xxii+230 pp., 27 pls., 3 figs.

Bulletin 103. Source material for the social and ceremonial life of the Choctaw Indians (Swanton). vii+282 pp., 6 pls., 1 fig.

Bulletin 104. A survey of prehistoric sites in the region of Flagstaff, Arizona (Colton). vii+69 pp., 10 pls., 1 fig.

Bulletin 105. Notes on the Fox Wāpanōwiweni (Michelson). v+195 pp. 1 fig.

Bulletin 107. Karuk Indian myths (Harrington). v+34 pp.

REPORT OF THE AMERICAN HISTORICAL ASSOCIATION

The annual reports of the American Historical Association are transmitted by the association to the Secretary of the Smithsonian Institution and are communicated by him to Congress, as provided by the act of incorporation of the association.

The annual report for 1930, volume 1, and the supplemental volume to the report for 1928 were issued during the year. The annual reports for 1930, volumes 3 and 4, and 1931, volume 1, and the supplemental volume to the report for 1929 were in press at the close of the year.

REPORT OF THE NATIONAL SOCIETY, DAUGHTERS OF THE AMERICAN
REVOLUTION

The manuscript of the Thirty-fourth Annual Report of the National Society, Daughters of the American Revolution, was transmitted to Congress, in accordance with law, November 9, 1931.

ALLOTMENTS FOR PRINTING

The congressional allotments for the printing of the Smithsonian report to Congress and the various publications of the Government bureaus under the administration of the Institution were virtually used up at the close of the year. The appropriation for the coming year ending June 30, 1933, totals \$60,000, allotted as follows:

Annual report to the Congress of the Board of Regents of the Smithsonian Institution.....	\$8, 850
National Museum.....	23, 250
Bureau of American Ethnology.....	14, 500
National Gallery of Art.....	100
International Exchanges.....	100
International Catalogue of Scientific Literature.....	50
National Zoological Park.....	150
Astrophysical Observatory.....	1, 000
Annual report of the American Historical Association.....	12, 000

Respectfully submitted.

W. P. TRUE, *Editor.*

Dr. CHARLES G. ABBOT,
Secretary, Smithsonian Institution.

REPORT OF THE EXECUTIVE COMMITTEE OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION FOR THE YEAR ENDED JUNE 30, 1932

To the Board of Regents of the Smithsonian Institution:

Your executive committee respectfully submits the following report in relation to the funds of the Smithsonian Institution, together with a statement of the appropriations by Congress for the Government bureaus in the administrative charge of the Institution:

SMITHSONIAN ENDOWMENT FUND

The original bequest of James Smithson was £104,960 8 shillings, 6 pence—\$508,318.46. Refunds of money expended in prosecution of the claim, freights, insurance, etc., together with payment into the fund of the sum of £5,015 which had been withheld during the lifetime of Madame de la Batut, brought the fund to the amount of..... \$550, 000. 00

Since the original bequest the Institution has received gifts from various sources, chiefly in the years prior to 1893, the income from which may be used for the general work of the Institution. To these gifts has been added capital from savings on income, gain from sale of securities, etc., bringing the total endowment for general purposes to the amount of..... 1, 039, 351. 68

The Institution holds also a number of endowment gifts the income of each being restricted to specific use. These are invested and stand on the books of the Institution as follows:

Arthur, James, fund, income for investigations and study of sun and lecture on the sun.....	\$50, 699. 31
Bacon, Virginia Purdy, fund, for a traveling scholarship to investigate fauna of countries other than the United States.....	63, 512. 52
Baird, Lucy H., fund, for creating a memorial to Secretary Baird.....	9, 959. 05
Barstow, Frederic D., fund, for purchase of animals for the Zoological Park.....	964. 27
Canfield collection fund, for increase and care of the Canfield collection of minerals.....	48, 488. 51
Casey, Thomas L., fund, for maintenance of the Casey collection and promotion of researches relating to Coleoptera.....	9, 797. 14
Chamberlain, Francis Lea, fund, for increase and promotion of Isaac Lea collection of gems and mollusks.....	35, 698. 68
Hodgkins fund, specific, for increase and diffusion of more exact knowledge in regard to nature and properties of atmospheric air..	100, 000. 00
Hughes, Bruce, fund, to found Hughes alcove.....	19, 205. 63
Myer, Catherine Walden, fund, for purchase of first-class works of art for the use of and benefit of the National Gallery of Art.....	22, 907. 94

Pell, Cornelia Livingston, fund, for maintenance of Alfred Duane Pell collection.....	\$3, 060. 69
Poore, Lucy T., and George W., fund, for general use of the Institution when principal amounts to the sum of \$250,000.....	62, 842. 17
Reid, Addison T., fund, for founding chair in biology in memory of Asher Tunis.....	25, 478. 94
Roebling fund, for care, improvement, and increase of Roebling collection of minerals.....	152, 987. 77
Rollins, Miriam and William, fund, for investigations in physics and chemistry.....	53, 787. 00
Springer, Frank, fund, for care, etc., of Springer collection and library.....	13, 835. 00
Walcott, Charles D. and Mary Vaux, research fund, for development of geological and paleontological studies and publishing results thereof.....	12, 450. 72
Younger, Helen Walcott, fund, held in trust.....	49, 812. 50
Zerbee, Frances Brincklé, fund, for endowment of aquaria.....	964. 84
<hr/>	
Total endowment for specific purposes other than Freer endowment.....	736, 452. 68

FREER GALLERY OF ART FUND

Early in 1906, by deed of gift, Charles L. Freer, of Detroit, gave to the Institution his collection of Chinese and other oriental objects of art, as well as paintings, etchings, and other works of art by Whistler, Thayer, Dewing, and other artists. Later he also gave funds for the construction of a building to house the collection, and finally, in his will, probated November 6, 1919, he provided stock and securities to the estimated value of \$1,958,591.42 as an endowment fund for the operation of the gallery. In view of the importance and special nature of the gift and the requirements of the testator in respect to it, all Freer funds are kept separate from the other funds of the Institution, and the accounting in respect to them is stated separately.

The invested funds of the Freer bequest are classified as follows:

Court and grounds fund.....	\$580, 016. 22
Court and grounds maintenance fund.....	145, 171. 79
Curator fund.....	589, 763. 31
Residuary legacy.....	3, 858, 208. 44
<hr/>	
Total.....	5, 173, 159. 76

SUMMARY

Invested endowment for general purposes.....	\$1, 039, 351. 68
Invested endowment for specific purposes other than Freer endowment.....	736, 452. 68
<hr/>	
Total invested endowment other than Freer endowment.....	1, 775, 804. 36
Freer invested endowment for specific purposes.....	5, 173, 159. 76
<hr/>	
Total invested endowment for all purposes.....	6, 948, 964. 12

CLASSIFICATION OF INVESTMENTS

Deposited in the United States Treasury at 6 per cent per annum as authorized in the United States Revised Statutes, section 5591-----		\$1,000,000.00
Investments other than Freer endowment:		
Bonds-----	\$309,191.11	
Stocks-----	459,773.42	
Real estate first-mortgage notes-----	6,500.00	
Uninvested capital-----	339.83	
		<u>775,804.36</u>
Total investments other than Freer endowment-----		1,775,804.36
Investments of Freer endowment:		
Bonds-----	\$2,623,665.18	
Stocks-----	2,465,015.68	
Real estate first-mortgage notes-----	61,000.00	
Uninvested capital-----	23,478.90	
		<u>5,173,159.76</u>
Total investments-----		6,948,964.12

CASH BALANCES, RECEIPTS, AND DISBURSEMENTS DURING THE FISCAL
YEAR ¹

Cash balance on hand June 30, 1931-----	\$224,221.84
Receipts:	
Cash from invested endowments and from miscellaneous sources for general use of the Institution-----	\$72,209.95
Cash gifts for increase of endowments for specific use-----	300.00
Cash gifts for increase of endowments for general use-----	100,000.00
Cash gifts, etc., for specific use (not to be invested)-----	33,761.71
Cash received as royalties from sales of Smithsonian Scientific Series-----	12,317.36
Cash income from endowments for specific use other than Freer endowment and from miscellaneous sources (including refund of temporary advances)-----	48,498.02
Cash capital from sale, call of securities, etc. (to be reinvested)-----	55,017.27
	<u>322,104.31</u>
Total receipts other than Freer endowment-----	322,104.31
Cash receipts from Freer endowment—income from investments-----	281,476.85
Gain from sale, etc., of securities-----	2,819.50
Cash capital from sale, call of securities, etc. (to be reinvested)-----	479,009.62
	<u>763,305.97</u>
Total-----	1,309,632.12

¹ This statement does not include Government appropriations under the administrative charge of the Institution.

Disbursements:

From funds for general work of the Institution—

Buildings, care, repairs, and alterations----	\$3, 282. 65
Furniture and fixtures-----	402. 64
General administration ² -----	28, 075. 92
Library-----	3, 078. 20
Publications (comprising preparation, printing, and distribution)-----	22, 317. 21
Researches and explorations-----	17, 768. 42
International exchanges-----	4, 287. 72

\$79, 212. 76

From funds for specific use, other than Freer endowment—

Investments made from gifts, from gain from sales, etc., of securities and from savings on income-----	7, 653. 23
Other expenditures, consisting largely of research work, travel, increase and care of special collections, etc., from income of endowment funds and from cash gifts for specific use (including temporary advances)-----	111, 071. 37
Reinvestment of cash capital from sale, call of securities, etc-----	56, 294. 40

175, 019. 00

From Freer endowment—

Operating expenses of the gallery, salaries, purchases of art objects, field expenses, etc-----	327, 575. 69
Investments made from gain from sale, etc., of securities and from income-----	26, 825. 40
Reinvestment of cash capital, from sale, call of securities, etc-----	450, 728. 68

805, 129. 77

Balance June 30, 1932-----	250, 270. 59
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Total----- 1, 309, 632. 12

EXPENDITURES FOR RESEARCHES IN PURE SCIENCE, EXPLORATIONS, CARE, INCREASE, AND STUDY OF COLLECTIONS, ETC.

Expenditures from general endowment:

Publications-----	\$22, 317. 21
Researches and explorations-----	17, 768. 42

\$40, 085. 63

Expenditures from funds devoted to specific purposes:

Researches and explorations-----	71, 098. 02
Care, increase, and study of special collections--	7, 320. 19
Publications-----	22, 766. 39

101, 184. 60

Total----- 141, 270. 23

² This includes salaries of the Secretary and certain others.

Table showing growth of endowment funds of the Smithsonian Institution

Year	Endowment for general work of the Institution, being original Smithsonian bequest, gifts from other sources, and invested savings of income	Endowment for specific researches etc., including invested savings of income	Freer gift for construction of Freer Gallery of Art Building	Freer bequest for operation of Freer Gallery of Art including salaries, care, etc.
1846-1891	¹ \$702, 000. 00			
1892	802, 000. 00	\$101, 000. 00		
1893-1894	852, 000. 00	101, 000. 00		
1895-1903	877, 000. 00	102, 000. 00		
1904-1913	885, 807. 58	111, 692. 42		
1914	885, 807. 58	116, 692. 42		
1915	886, 084. 02	143, 515. 98		
1916	887, 607. 08	160, 527. 30	\$1, 000, 000. 00	
1917	887, 830. 00	164, 304. 38		
1918	² 883, 867. 00	176, 157. 38		
1919	884, 305. 00	190, 489. 38		
1920	884, 747. 00	198, 149. 02		
1921	884, 933. 74	272, 538. 31	³ 367, 072. 04	\$1, 253, 004. 75
1922	886, 107. 14	291, 858. 14		1, 842, 144. 75
1923	886, 246. 14	306, 524. 14		⁴ 3, 296, 574. 75
1924	886, 373. 31	319, 973. 19		3, 401, 355. 42
1925	886, 769. 73	338, 136. 77		3, 459, 705. 34
1926	886, 830. 13	342, 876. 37		3, 714, 361. 23
1927	886, 877. 79	498, 401. 96		4, 171, 880. 61
1928	929, 068. 21	665, 233. 29		4, 268, 244. 26
1929	⁵ 1, 022, 385. 75	626, 003. 70		5, 236, 054. 02
1930	1, 033, 789. 85	636, 792. 55		5, 300, 929. 50
1931	1, 045, 965. 33	701, 916. 19		5, 367, 711. 51
1932	1, 039, 351. 68	736, 452. 68		5, 173, 159. 76

¹ Original endowment plus income from savings during these years.² Loss on account of bonds reduced on books from par to market value.³ Cash from sale of 2,000 shares of Parke, Davis & Co. stock, including dividends, and interest on gift of \$1,000,000.⁴ In this year Parke, Davis & Co. declared 100 per cent stock dividend.⁵ Increase largely from funds transferred from specific endowment column and income released for general work of the Institution.

BALANCE SHEET OF THE SMITHSONIAN INSTITUTION JUNE 30, 1932

ASSETS

Stocks, bonds, etc., at acquirement value:

Consolidated fund	\$711, 817. 03
Freer Bequest	5, 149, 680. 86
Springer fund	13, 835. 00
Younger fund	49, 812. 50

\$5, 925, 145. 39

United States Treasury deposit 1, 600, 000. 00

Miscellaneous, principally funds advanced for printing publications, and field expenses (to be repaid) 76, 678. 41

Cash:

Funds in United States Treasury and in banks	\$250, 270. 59
In office safe, for cash transactions	1, 900. 00

252, 170. 59

7, 253, 994. 39

LIABILITIES

Freer bequest, capital accounts:

Court and grounds fund.....	\$580, 016. 22
Court and grounds maintenance fund.....	145, 171. 79
Curator fund.....	589, 763. 31
Residuary estate fund.....	3, 858, 208. 44
	<hr/> \$5, 173, 159. 76

CAPITAL ACCOUNTS

Arthur, James, fund.....	50, 699. 31
Bacon fund.....	63, 512. 52
Baird fund.....	9, 959. 05
Barstow, Frederic D., fund.....	964. 27
Canfield collection fund.....	48, 488. 51
Casey, Thomas Lincoln, fund.....	9, 797. 14
Chamberlain fund.....	35, 698. 68
Hodgkins fund, specific.....	100, 000. 00
Hughes, Bruce, fund.....	19, 205. 63
Myer fund.....	22, 907. 94
Pell fund.....	3, 060. 69
Poore fund.....	62, 842. 17
Reid fund.....	25, 478. 94
Roebbling collection fund.....	152, 987. 77
Rollins, Miriam and William, fund.....	53, 787. 00
Smithsonian unrestricted fund.....	1, 039, 351. 68
Springer fund.....	13, 835. 00
Walcott research fund.....	12, 450. 72
Younger fund.....	49, 812. 50
Zerbee, Frances Brincklé, fund.....	964. 84

CURRENT ACCOUNTS

Freer bequest.....	66, 306. 11
Springer fund.....	5, 265. 41
Younger fund.....	217. 50
Miscellaneous accounts held by the Institution for the most part for specific use.....	233, 241. 25
Total.....	<hr/> 7, 253, 994. 39

During the year, the Institution received as gifts a total of approximately \$135,000, which included donations for specific uses not to be invested, for increase of endowments for specific purposes, and a bequest of \$100,000 for the increase of the general endowment fund.

All payments are made by check, signed by the Secretary of the Institution, on the Treasurer of the United States, and all revenues are deposited to the credit of the same account. In many instances deposits are placed in bank for convenience of collection and later are withdrawn in round amounts and deposited in the Treasury.

The practice of investing temporarily idle funds in time deposits has proven satisfactory. During the year the interest derived from this source has resulted in a total of \$5,364.02.

The foregoing report relates only to the private funds of the Smithsonian Institution. The following is a statement of the congressional

appropriations for the past 10 years for the support of the several governmental branches under the administrative control of the Institution and of appropriations for other special purposes during that period.

Table showing the appropriations made by Congress during the last 10 years, intrusted to the care of the Smithsonian Institution

Year	International exchanges	American ethnology	Cooperative ethnological researches	International Catalogue of Scientific Literature	Astro-physical Observatory	Increase of compensation	National Museum	Gellatly art collection
1923.....	\$45,000	\$44,000	-----	\$7,500.00	\$15,500	\$109,044	\$418,120	-----
1924.....	43,000	44,000	-----	7,500.00	15,500	112,704	415,000	-----
1925.....	49,550	57,160	-----	8,861.66	21,580	-----	547,292	-----
1926.....	46,260	57,160	-----	8,000.00	131,180	-----	554,392	-----
1927.....	46,260	57,160	-----	7,500.00	31,180	-----	565,820	-----
1928.....	46,855	58,720	-----	7,260.00	32,060	-----	606,960	-----
1929.....	50,355	65,800	\$20,000	7,885.00	36,630	-----	701,524	-----
1930.....	51,297	68,800	-----	7,885.00	36,720	-----	717,014	\$21,000
1931.....	52,810	70,840	-----	8,145.00	37,560	-----	793,894	20,000
1932.....	54,060	72,640	-----	8,150.00	37,620	-----	775,090	20,000

Year	Safeguarding done of Natural History Building	National Zoological Park	Additional for Zoological Park	National Gallery of Art	Printing and binding	Additional assistant secretary	Salaries and expenses	Additional fire protection
1923.....	-----	\$125,000	\$2,500	\$15,000	\$77,400	-----	-----	-----
1924.....	-----	125,000	-----	16,000	77,400	-----	-----	-----
1925.....	-----	151,487	-----	20,158	90,000	\$6,000	-----	\$8,500
1926.....	-----	157,000	-----	21,028	90,000	6,000	-----	-----
1927.....	-----	173,199	-----	29,381	90,000	6,000	-----	-----
1928.....	-----	175,000	\$25,000	30,356	90,000	7,500	-----	-----
1929.....	\$80,000	195,550	\$30,000	35,273	95,000	-----	\$35,804	-----
1930.....	-----	203,000	\$222,000	34,853	95,000	-----	36,004	-----
1931.....	-----	220,520	\$28,000	45,218	99,000	-----	38,804	-----
1932.....	-----	255,540	\$4,500	45,220	104,000	-----	38,644	-----

¹ Increase in appropriation due to Government assuming part of the expenses of the Chilean Station, which up to this time had been supported by private funds of the Smithsonian Institution.

² Increases over former figures due to passage of Welch Act.

³ Building for birds.

⁴ After 1923 this item is included in appropriation for salaries and expenses.

⁵ Work done by Supervising Architect and funds disbursed by United States Treasury.

⁶ Building for reptiles, etc., \$220,000; gates for south boundary of park, \$2,000.

⁷ Includes plans for additions to Natural History Building, \$10,000.

⁸ Additional for building for reptiles.

⁹ Plans for building for small mammals.

The report of the audit of the Smithsonian private funds is printed below.

OCTOBER 1, 1932.

EXECUTIVE COMMITTEE, BOARD OF REGENTS,

Smithsonian Institution, Washington, D. C.

SIRS: Pursuant to agreement we have audited the accounts of the Smithsonian Institution for the fiscal year ended June 30, 1932, and certify the balance of cash on hand June 30, 1932, to be \$252,170.59.

We have verified the record of receipts and disbursements maintained by the Institution and the agreement of the book balances with the bank balances.

We have examined all the securities in the custody of the Institution and in the custody of the banks and found them to agree with the book records.

We have compared the stated income of such securities with the receipts of record and found them in agreement therewith.

We have examined all vouchers covering disbursements for account of the Institution during the fiscal year ended June 30, 1932, together with the authority therefor, and have compared them with the Institution's record of expenditures and found them to agree.

We have examined and verified the accounts of the Institution with each trust fund.

We found the books of account and records well and accurately kept and the securities conveniently filed and securely cared for.

All information requested by your auditors was promptly and courteously furnished.

We certify the Balance Sheet, in our opinion, correctly presents the financial condition of the Institution as at June 30, 1932.

WILLIAM L. YAEGER & Co.,

WILLIAM L. YAEGER,

Certified Public Accountant.

Respectfully submitted.

FREDERIC A. DELANO

R. WALTON MOORE

JOHN C. MERRIAM

Executive Committee.

PROCEEDINGS OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION FOR THE FISCAL YEAR ENDED JUNE 30, 1932

ANNUAL MEETING, DECEMBER 10, 1931

Present: Chief Justice Charles Evans Hughes, chancellor, in the chair, Senator Reed Smoot, Senator Joseph T. Robinson, Senator Claude A. Swanson, Representative Albert Johnson, Representative Robert Luce, Hon. R. Walton Moore, Frederic A. Delano, Dr. John C. Merriam, and the secretary, Dr. C. G. Abbot. Dr. Alexander Wetmore, assistant secretary, was also present.

The secretary announced that on March 3, 1931, the President pro tempore of the Senate appointed Senator Joseph R. Robinson as a Regent to succeed himself.

Mr. Delano, chairman of the executive committee, offered the following resolution, which was adopted:

Resolved, That the income of the Institution for the fiscal year ending June 30, 1933, be appropriated for the service of the Institution, to be expended by the secretary, with the advice of the executive committee, with full discretion on the part of the secretary as to items.

The secretary submitted his annual report to June 30, 1931, and added a résumé, prepared by the editor, relating to publications issued by the Institution during the year. The editorial work of the Institution had been reorganized for the sake of greater unity of policy and increased efficiency. Instead of maintaining three separate editorial offices as formerly, the responsibility for all of the 13 series issued under the Institution was centered in the editor of the Smithsonian proper, and all of the editorial staff was moved into a group of offices close together on the third floor of this building.

Mr. Delano presented the report of the executive committee for the fiscal year ending June 30, 1931, showing the financial condition of the Institution for that period.

The annual report of the National Gallery of Art Commission was accepted, and the board adopted the following resolutions:

Resolved, That the Board of Regents of the Smithsonian Institution hereby approves the recommendation of the National Gallery of Art Commission that James E. Fraser, J. H. Gest, F. J. Mather, jr., and E. C. Tarbell, be reelected as members of the commission for the ensuing term of four years, their present terms having expired.

Resolved, That the Board of Regents of the Smithsonian Institution hereby approves the recommendation of the National Gallery of Art Commission that

the three vacancies in the commission caused by the death of members, be filled by the election of George B. McClellan to succeed W. K. Bixby, Thomas Cochran to succeed James Parmelee, and Paul Manship to succeed Daniel Chester French.

The secretary reported that the Langley Gold Medal, awarded to Admiral Richard Evelyn Byrd, had been presented on March 27, 1931, and that this ceremony had been noted in the previous annual report.

The secretary said that the Regents were aware of the death of Senator Dwight W. Morrow on October 5, 1931. He had been a Regent of the Institution for nearly five years when his membership on this Board was terminated automatically by his induction, on December 3, 1930, as a Senator from New Jersey.

Mr. Moore offered the following resolutions which were adopted:

Whereas death has removed from his career of usefulness to our country and the world the late Dwight W. Morrow, Senator from New Jersey, and

Whereas during his too brief service as Regent of the Smithsonian Institution—from January 7, 1926, to December 3, 1930—Mr. Morrow gave unstintingly of his time and counsel to promote the vital interests of the Institution, and inaugurated movements of exceptional value to it, and

Whereas by generous gifts during his lifetime and by a large unconditional bequest he has greatly increased the endowment of the Institution: Therefore be it

Resolved, That the Board of Regents of the Smithsonian Institution hereby expresses its profound sense of loss to the Nation and to the Institution in the passing of Senator Morrow; and be it further

Resolved, That these resolutions be spread upon the minutes of the board, and that a copy be sent, with an expression of our deepest sympathy, to the family of Mr. Morrow.

The secretary stated that John Gellatly died November 8, 1931. It will be recalled that in 1929 and in 1930 Mr. Gellatly gave his great collection of art objects to the Institution for eventual exhibition in the National Gallery of Art.

The secretary said that the attention of the board had been called to a bequest to the Institution by James Arthur, of New York City, the income of which was to be used for (a) the investigation and study of the sun; (b) to provide annually a lecture to be known as The James Arthur Annual Lecture on the Sun. The first Arthur lecture would be given by the distinguished astronomer, Dr. Henry Norris Russell, of Princeton University, on January 27, 1932.

The board had been informed that through the generosity of Ambassador Dawes, Dr. Charles Upson Clark had been engaged for over two years in conducting researches in European archives, the special objective being a search for early native and Spanish documents relating to the Indians of the period of the Conquest, or earlier. The secretary added that the matter collected by Doctor Clark was being prepared for publication, though at this time there was no money available for that purpose. He hoped, however, that at some future time means might be secured to publish this valuable material.

The secretary said that royalties were being received from the sale of the Smithsonian Scientific Series. These now totaled \$53,510.46 in cash, and further returns were to be expected in the years to come.

The secretary then spoke of the work being conducted under generous grants from John A. Roebling and the Research Corporation, and also of the gratifying results of the sales of the volumes of North American Wild Flowers; after which Doctor Wetmore made a statement of the exploration work done by members of the National Museum staff. This was followed by an explanation of the proposed additions to the present Museum building, during which the plans for this construction were exhibited.

The secretary concluded his statement with a brief description of the work done in the field by ethnologists of the Bureau of American Ethnology, and also of the results accomplished at the National Zoological Park.

REGULAR MEETING OF FEBRUARY 11, 1932

Present: Chief Justice Charles Evans Hughes, chancellor, in the chair, Senator Joseph T. Robinson, Representative Albert Johnson, Representative Andrew J. Montague, Representative T. Alan Goldsborough, and the secretary, Dr. C. G. Abbot. Dr. Alexander Wetmore, assistant secretary, was also present.

The secretary reported that on December 16, 1931, the Speaker of the House of Representatives had appointed Albert Johnson, of Washington, to succeed himself; and Andrew J. Montague, of Virginia, and T. Alan Goldsborough, of Maryland, to succeed R. Walton Moore and Robert Luce, respectively.

The secretary read a letter from Mrs. Elizabeth C. Morrow expressing appreciation of the resolutions adopted by the board upon the death of her husband, Senator Dwight W. Morrow. He then gave a brief history of the origin and establishment of the Research Corporation, stating that during the last few years it had made grants to the Institution for conducting certain researches in the growth of plant life by the Division of Radiation and Organisms. He explained the nature of this work and the importance of the sun's rays to human, animal, and plant life.

He stated also that the Research Corporation had made awards through the Smithsonian Institution of \$2,500 each to Dr. Andrew Ellicott Douglass and to Dr. Ernst Antevs for work in their respective lines, relating to chronology and periodicity in weather, and that these awards had been presented by the chancellor at a ceremony recently. The presentations were followed by addresses by the recipients.

The secretary announced that the first lecture under the James Arthur bequest was delivered January 27, 1932, by Dr. Henry

Norris Russell, of Princeton University, and that on February 24 Dr. Aleš Hrdlička, Curator of the Division of Physical Anthropology of the National Museum, would lecture upon his recent researches in Alaska; also that on March 30 a lecture would be given by Dr. A. C. Seward, Master of Downing College, Cambridge University, a noted English botanist.

The secretary then referred to the project for the addition of wings to the present National Museum Building, and requested Doctor Wetmore to explain the matter.

Doctor Wetmore exhibited the plans for these additions, which had been prepared by the Allied Architects of Washington, under the supervision of Nathan Wyeth. These were made possible by an appropriation of \$10,000 for this purpose. He described the proposed arrangement of exhibition halls, office rooms, and laboratories, and in answer to Mr. Johnson's inquiry explained that no appropriation for this construction was expected at this time, but that the matter had been brought before the House committee as a matter of record.

GENERAL APPENDIX
TO THE
SMITHSONIAN REPORT FOR 1932

ADVERTISEMENT

The object of the GENERAL APPENDIX to the Annual Report of the Smithsonian Institution is to furnish brief accounts of scientific discovery in particular directions; reports of investigations made by collaborators of the Institution; and memoirs of a general character or on special topics that are of interest or value to the numerous correspondents of the Institution.

It has been a prominent object of the Board of Regents of the Smithsonian Institution from a very early date to enrich the annual report required of them by law with memoirs illustrating the more remarkable and important developments in physical and biological discovery, as well as showing the general character of the operations of the Institution; and, during the greater part of its history, this purpose has been carried out largely by the publication of such papers as would possess an interest to all attracted by scientific progress.

In 1880, induced in part by the discontinuance of an annual summary of progress which for 30 years previously had been issued by well-known private publishing firms, the secretary had a series of abstracts prepared by competent collaborators, showing concisely the prominent features of recent scientific progress in astronomy, geology, meteorology, physics, chemistry, mineralogy, botany, zoology, and anthropology. This latter plan was continued, though, not altogether satisfactorily, down to and including the year 1888.

In the report for 1889 a return was made to the earlier method of presenting a miscellaneous selection of papers (some of them original) embracing a considerable range of scientific investigation and discussion. This method has been continued in the present report for 1932.

SOLAR RADIATION¹

By C. G. ABBOT

Secretary, Smithsonian Institution

[With 3 plates]

Directly or indirectly our most important interests depend on the solar radiation. The sun rays keep the earth warm enough to sustain life. Variations of their intensity associated with summer and winter, and with night and day, produce climates. Slight variations of the original output of rays from the sun itself seem to be highly influential in altering the weather. All growth in plants depends upon the application of solar energy. Our atmosphere is the source of carbon, which is a principal plant constituent. The trifling percentage of carbonic-acid gas contained in air is the essential food of plants, but it can not nourish them without the help of radiation. The health of animals, including man, requires radiation. The prevention of rickets by the curious direct and indirect influences of ultra-violet rays has formed a fascinating chapter in the story of recent investigations.

Power is principally derived indirectly from solar radiation. Solar heat evaporates the oceans, drives the clouds inland, precipitates the rain and snow, and thus maintains the world's hydroelectric power sources. Enormous as these are, they are, nevertheless, trifling compared to the power derived from oil and coal. Oil, the less important of these two sources, comes mainly from animal life that was sustained ages ago by the vegetation fed by the ancient sun. Coal, on the other hand, is the end product of decomposition of vegetation. The enormous deposits of coal, which are now the world's principal sources of power, represent but a trifling percentage of the solar energy lavished on the earth in former geologic ages.

These are highly indirect applications of solar radiation for power supplies. It is possible, however, as numerous inventors have shown, to produce heat for driving engines by the direct absorption of solar rays. If the devices now available for this purpose should be but a

¹ Reprinted, by permission, from the Proceedings of the Ohio State Educational Conference, Eleventh Annual Session, The Ohio State University Bulletin, vol. 36, No. 3, Sept. 15, 1931.

little more improved, the desert regions of the world could supply cheap solar power in quantities beyond the extremest possibilities of future world demands. A lesser, but still interesting aspect of solar radiation, lies in its use for domestic purposes. Food may be cooked, and water may be heated by simple and inexpensive contrivances for utilizing solar radiation.

It may be that none of the services rendered to us by the sun is more important than its esthetic use. The colors of all flowers represent the fragments of the complete solar spectrum remaining after the pigments of the plant world have absorbed certain rays. Unabsorbed remainders are reflected and produce gorgeous mixtures of colors. Without the green of the grass and trees, the blue of the sky, the brilliant hues of flowers, and the more somber, but yet pleasing shades of the soil, and thousands of familiar objects on all sides, we should be sad indeed.

Though thus obviously so important, it is little more than a century since measurements began to be made of the intensity of the solar radiation. Pioneers in this investigation were C. S. M. Pouillet, Sir John Herschel, and J. D. Forbes. They all devised instruments adapted to absorb the solar radiation as completely as possible and thus to convert it into heat. By appropriate devices for measuring the heat thus produced, they obtained measurements of the intensity of solar radiation. So intimate is the association between radiation and heat that many people have confused the two. Yet they are distinct and different. Radiation comprises a mixture of impulses which traverse a vacuum at the enormous speed of 186,000 miles per second. These impulses are separable by prisms or gratings into innumerable regular periodicities. These periodicities produce different sensations of color in our eyes. Many of them, indeed, are invisible to us. Since radiation can traverse the vacuum and nevertheless seems to comprise transverse waves of exceeding shortness, philosophic minds have not been content to contemplate so great a paradox as waves traveling in nothingness. They have devised the idea of the luminiferous ether as a medium filling all space. At present, our ideas are in a state of flux regarding this abstruse subject, but at least we can think of radiation as something which can exist where there is no matter in the ordinary sense, for it comes to us across an immense void from the sun and the stars. Heat, on the contrary, is well recognized to be the motion of the molecules of material substances. The energy of radiation is competent to stir up this mode of motion called heat when, for instance, radiation is absorbed by a black object. If the object is "absolutely black," absorption is complete and all the energy of the ray is transformed into heat.

The measuring instruments of Pouillet, Herschel, Forbes, and others exposed surfaces blackened with lampblack. This substance is not quite "absolutely black," for it reflects away about 3 per cent of ordinary sun rays. Kirchhoff, about 70 years ago, proved that a closed chamber, whether blackened or not, must be a perfect absorber. However small the percentage of rays absorbed at one impact, there is no escape, and the rays must be reflected hither and thither until by innumerable impacts their intensity is reduced below any assignable minimum. This principle of the "absolutely black" chamber has been incorporated into the Smithsonian water-flow pyrheliometer. This instrument thus far is the world's standard for measuring solar radiation.

Assuming, therefore, that we have accomplished the complete absorption of the solar ray, and its entire transformation into heat, and have devised means for the exact measurement of the heat thus produced, we then may express the intensity of solar radiation at the earth's surface. We are accustomed to express it in terms of the amount of radiation absorbed upon a square centimeter of surface in a minute of time. We measure the heat produced in calories. In these terms we find the heat of solar radiation near noon on clear days to be approximately 1.4 calories per square centimeter per minute. To state the matter in more common terms, the solar radiation, if transformed completely into work, would produce roughly a horsepower per square yard whenever the sun is high in the sky. Thus even at 93,000,000 miles, the sun rays are tremendously powerful. The sun itself sends them out in every direction continually. This output equals the heat of the burning of 400,000,000,000,000,000,000,000 tons of anthracite coal per year.

Measurements of solar radiation at the earth's surface are subject to losses by absorption and scattering of the rays in our atmosphere. High up, at an altitude of nearly 40 miles, there exists a small quantity of ozone which is that form of oxygen whose molecules contain 3 atoms instead of the usual 2. Ozone is a complete absorber of all rays in the extreme ultra-violet from wave length 2,900 Å. onward for a considerable range. This is very fortunate. Otherwise our skin would be blistered and our eyes blinded, for these short-wave rays which are totally absorbed by ozone are highly destructive to animal tissues. On the other hand, it is not less fortunate that ozone allows some rays on the border of its absorption band to pass, for these rays between wave lengths 2,900 Å. and 3,100 Å. are indispensable to prevent rickets. The total thickness of gas of the atmospheric ozone layer, if it could be brought down to sea level, would be less than one-eighth of an inch. It is astonishing and even terrifying to contemplate the narrow margin of safety on which our lives

thus depend. Were this trifling quantity of atmospheric ozone removed, we should all perish. If it were ten times greater, we could not live. Rickets would prevail universally.

Other little-considered atmospheric gases of great importance to our comfort are water vapor and carbonic acid, both minor constituents of the air, quantitatively speaking. Without the water vapor, our earth, like the moon, would cool far below freezing every night within a few moments after the sun sinks below the horizon. Water vapor hinders the incoming rays of the sun to the extent of 10 to 15 per cent, but it hinders the escape of the long-wave rays emitted by the earth by over 70 per cent. Thus water vapor acts like the gardener's glass cover of his hotbed. It lets sun rays in profusely, but holds earth rays from escaping, and so is an efficient regulator of climate. Carbonic-acid gas also acts in a somewhat similar way, but less efficiently than water vapor. The indispensable function of carbonic-acid gas in our atmosphere is to be the essential food for plants.

Other atmospheric constituents which greatly modify the income and outgo of radiation for the earth's surface are clouds and dust. The permanent gases, oxygen and nitrogen, alter the incoming sun rays, it is true, but weaken them only slightly, and hardly alter the outgoing earth rays at all. The molecules of the permanent atmospheric gases, oxygen and nitrogen, scatter sun rays more and more powerfully toward the violet end of the spectrum. But what is thus lost to the direct solar beam comes to us almost wholly in the beautiful blue rays of the sky. Dust also scatters sun rays, but without much selection of color. A dusty sky is therefore nearly white. Sunset and sunrise owe their beautiful colors to the scattering of sun rays by the atmosphere. When the sun is near the horizon, its rays shine very obliquely through the atmosphere and therefore by enormously long paths. The consequence is that the powerful tendency to scattering of the blue and violet rays so far depletes that part of the spectrum that the sky light which reaches us has a yellow or even a red tinge. S. P. Langley, third secretary of the Smithsonian Institution, was a profoundly interested student of solar radiation and atmospheric absorption. He wrote:

If the observation of the amount of heat the sun sends the earth is among the most important and difficult in astronomical physics, it may also be termed the fundamental problem of meteorology, nearly all whose phenomena would become predictable, if we knew both the original quantity and kind of this heat; how it affects the constituents of the atmosphere on its passage earthward; how much of it reaches the soil; how, through the aid of the atmosphere, it maintains the surface temperature of this planet; and how, in diminished quantity and altered kind, it is finally returned to outer space.²

² Langley, S. P., Report of the Mount Whitney Expedition, Prof. Pap. Signal Service, No. 15, p. 11, 1884.

Fifty years ago Langley invented the bolometer, an exquisitely delicate electrical thermometer sensitive to a millionth of a degree. He took it to Mount Whitney, Calif., in 1881, to measure the rays of the solar spectrum under the purest of skies. He also perfected and applied a method for determining the losses suffered by solar rays in traversing the turbid and absorbing ocean of atmosphere which always overlies even the choicest of observing stations. With some improvements, we still use the Langley bolometer and the Langley method.

For the past 12 years the Smithsonian Institution has maintained stations on high mountains in desert lands where daily measurements of the solar radiation are made. Our best station, at Mount Montezuma, Chile, 9,000 feet in altitude, lies in a desert where rain seldom falls and where neither animal nor vegetable life can exist. The observers must bring even water itself from the town 12 miles distant. The observations are carried on in such a way that the losses caused by the atmosphere are determined accurately. Thus we are able to measure the intensity of solar radiation as it would be found outside our atmosphere altogether, as if one were on the moon, for instance. We allow for the ellipticity of the earth's orbit, and thus reduce the results to a constant solar distance. Following long custom, we call the resulting value "the solar constant of radiation." It is on the average 1.94 calories per square centimeter per minute.

Yet the solar-radiation intensity is not perfectly constant. It varies through a range of several per cent. Figure 1 shows how two of our stations, one at Montezuma, Chile, the other at Table Mountain, Calif., agree within 0.2 per cent in tracing the variation of it by their monthly mean results over the past five years. The total range of variation shown by these monthly means is 1.5 per cent. Figure 2 shows in curve A the monthly Montezuma values since 1918. The total range in this period is 2.5 per cent. Curves C, D, E, F, G are regular periodic curves of 68, 45, 25, 11, and 8 months whose sum, given in curve B, almost exactly reproduces the variation shown in the original observations given by curve A. Other shorter periods may be found in solar variation, as indicated for the year 1924 in curve H. I have ventured to forecast in curve I the probable march of solar variation in the years 1931 and 1932.³

Short-interval changes are also found as shown in Figure 3. I have indicated by curved lines, full and dotted, respectively, over 100 cases each of rising and of falling sequences extending over several days each. The smallest ranges considered in these short-period changes are 0.45 per cent, and the largest found is 2.5 per cent. I have compared with these sequences the weather of Washington,

³Footnote added January 1933: The observations of 1931 and 1932 closely verified this prediction.

Williston, and Yuma. The interesting result comes out that both temperatures and barometric pressures in weather show opposite courses depending on whether they accompany and follow rising or falling solar radiation. This is shown for Washington weather in Figure 4. Apparently major changes in weather are caused by small fluctuations in the solar radiation.

If this is so, we ought to expect that the regular periodicities which are proved by Figure 2 to comprise the principal solar changes since 1918 ought to be reflected in the weather. In Figure 5 one may see that this is indeed so. The principal changes in Washington temperatures since 1918 are represented as the sum of six regular periodicities, of which five are those found in the solar radiation. This gives us hope that weather may be susceptible to long-range forecasting. It would, indeed, be a great boon if the characteristics of coming seasons and years could thus be approximately known in advance. But much further study must be made before this hope can be thoroughly tested.

We see from these exhibits that solar variation is of two types, the long range and the short range, respectively. Two kinds of causes probably are involved. The long periods of 68, 45, 25, 11, and 8 months are closely related to the well-known interval of $11\frac{1}{4}$ years in which the numbers of sun spots wax and wane. This suggests that these longer-range periodicities are due to increasing and decreasing agitation in the gaseous fluid

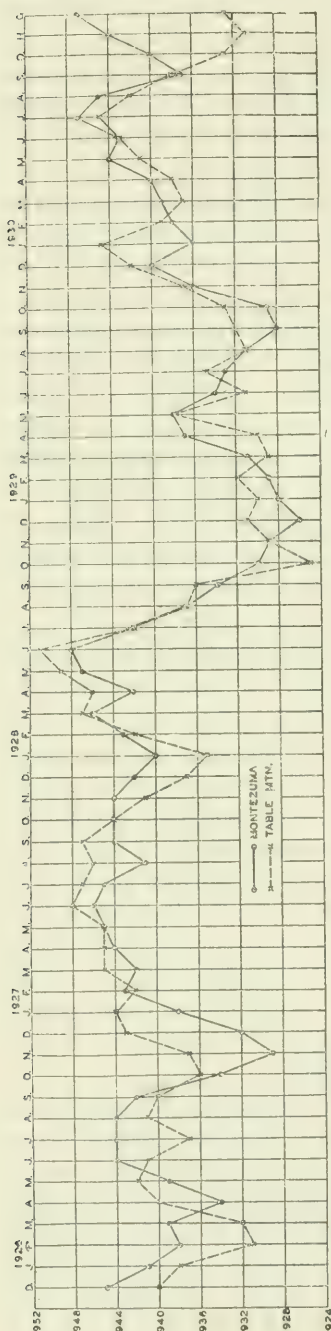


FIGURE 1.—Variation of the sun's radiation. Comparative results of monthly mean observations 5,000 miles apart at Montezuma, Chile, and Table Mountain, Calif. The two stations agree on it within an average discrepancy of 0.2 per cent

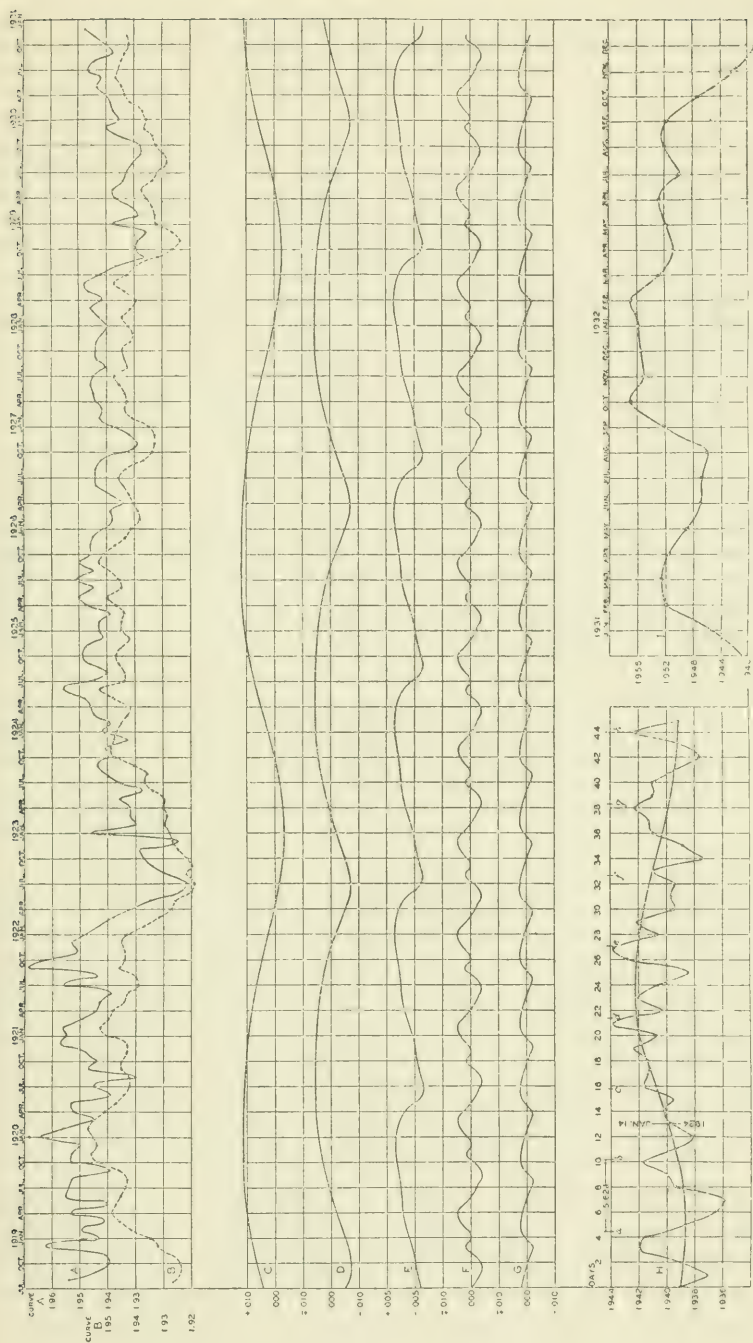


FIGURE 2.—Periodicities in solar variation. Monthly mean solar-constant values 1918 to 1930, analyzed into periodicities of 65, 45, 25, 11, and 8 months, shown in curves C, D, E, F, G. Their sum in curve H closely parallels the original curve A. The years 1931 and 1932 forecast, curve I. Periodicals of shorter length found in 1924, curve H

which composes the sun. It is to be regarded like the stirring of a fire with a poker, which brings up from below the hotter materials, and throws out temporarily a greater radiation in our rooms.

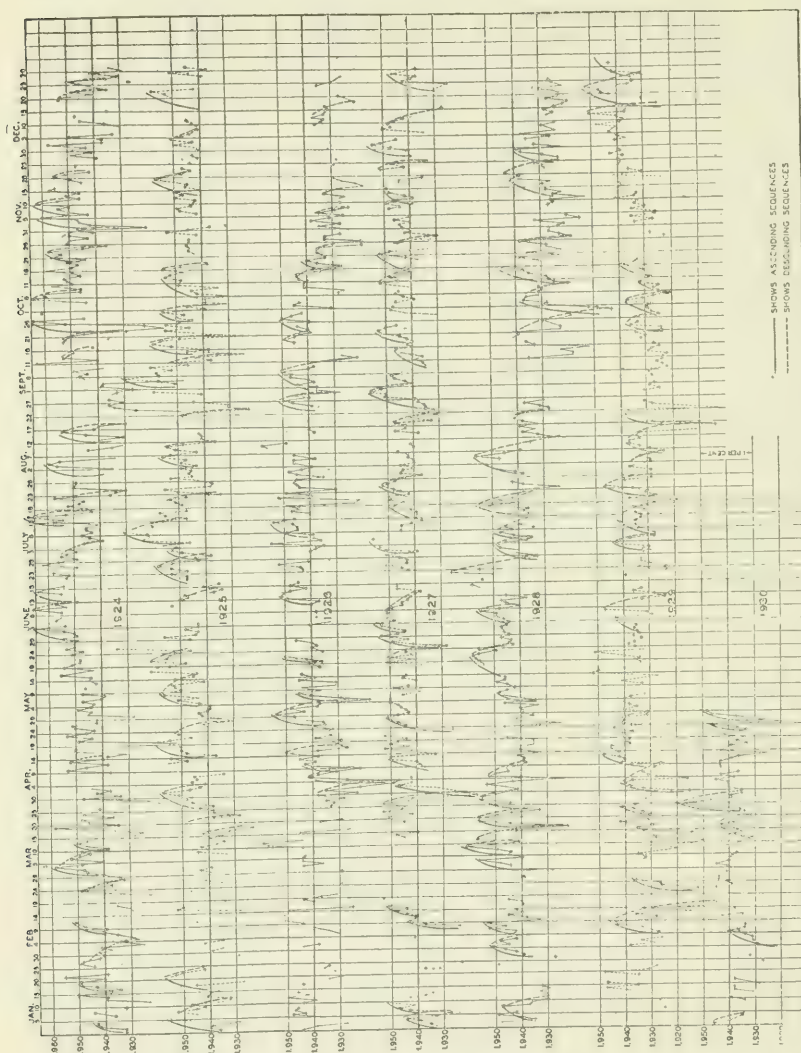


Figure 3.—Solar variation, 1924 to 1930. Daily observations at the Smithsonian Station, Montezuma, Chile. Circles, satisfactory; dresses, nearly satisfactory; points, unsatisfactory. Rising and falling sequences of solar changes are indicated by full and dotted curves, respectively

The short-period changes of solar radiation, which run their courses in a few days, are probably caused in other ways. We may suppose that patches of increased or diminished radiating power form occasionally on the solar surface. An example of this, indeed, is often seen in the bright faculae which surround sun spots. On the other hand, there may be areas of diminished intensity above the sun

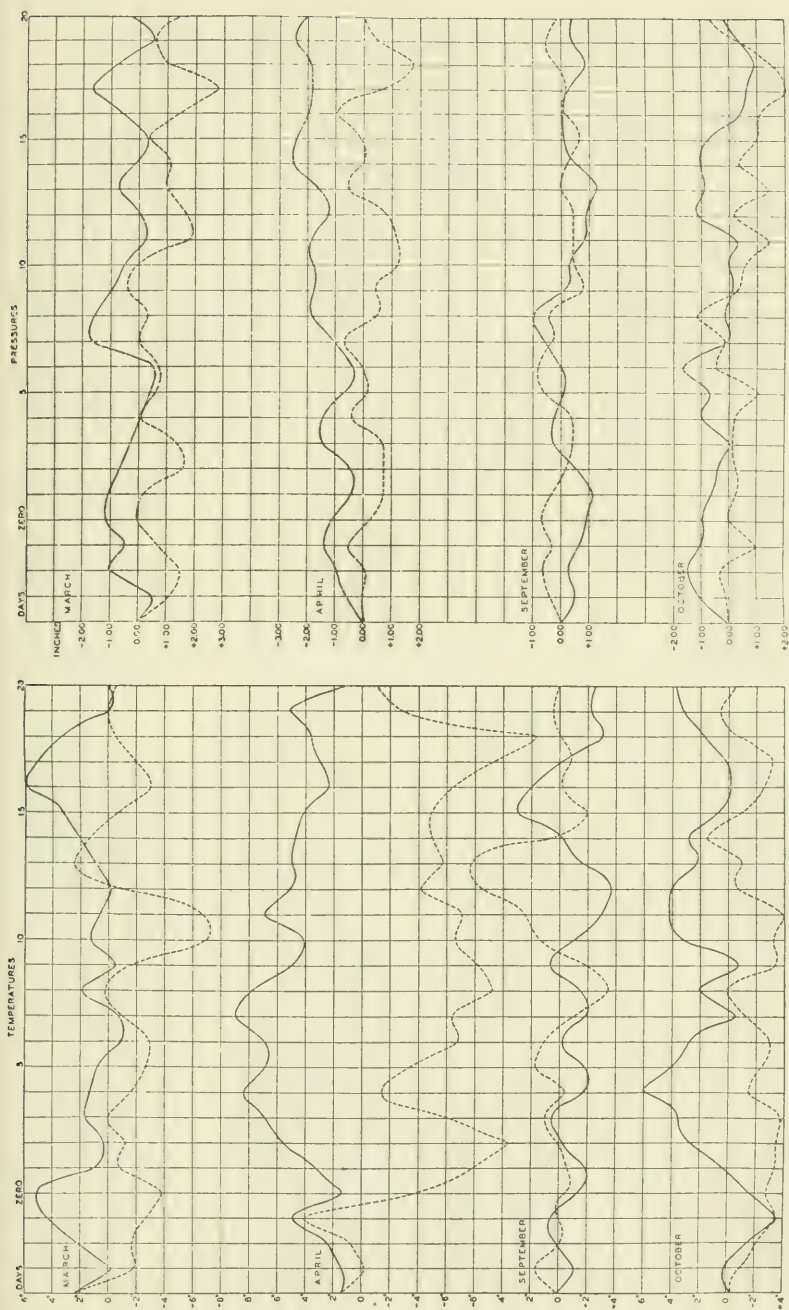


FIGURE 4.—Washington temperatures and pressures associated with and following sequences of solar change shown in Figure 3. The results given here are average results of a period of seven years. Note the opposition between the full and dotted curves corresponding to rising and falling solar radiation, respectively

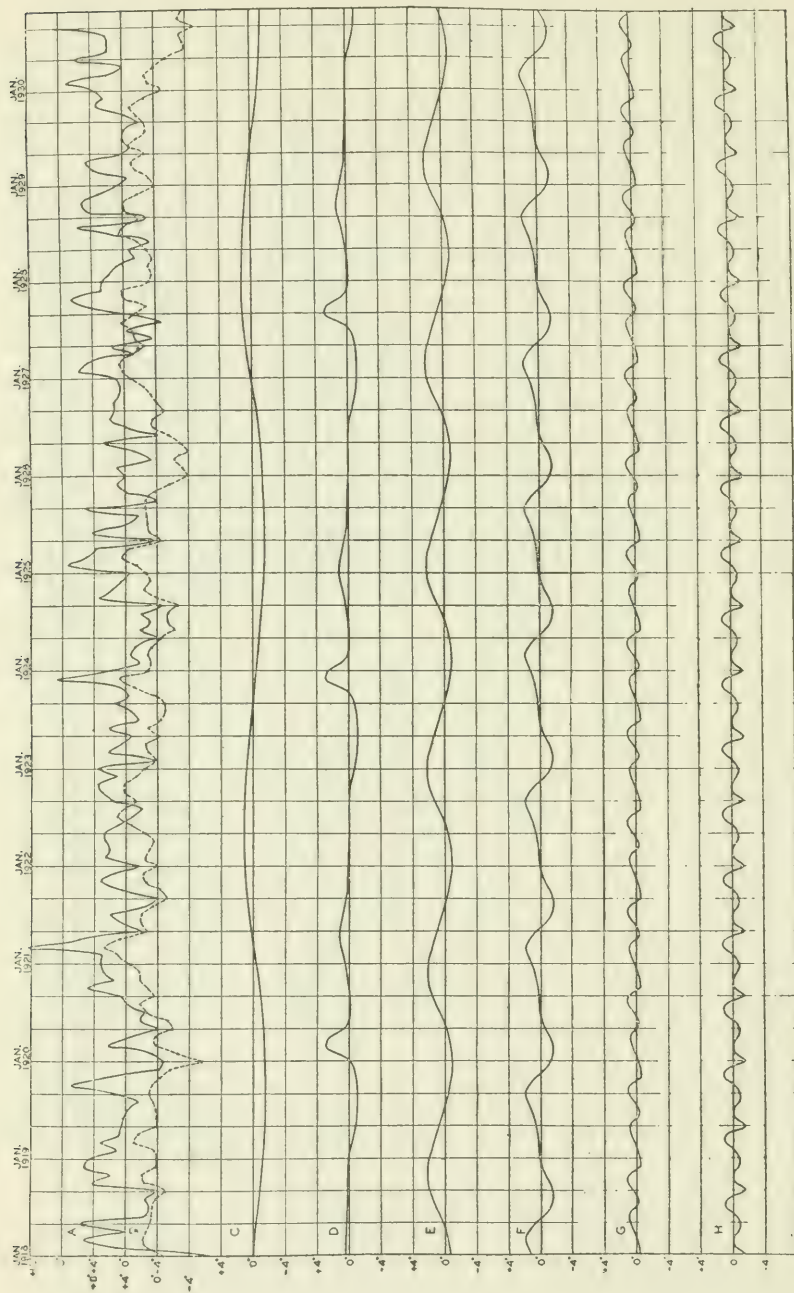


FIGURE 5.—Periodicities in Washington temperature associated with the periodicities in solar radiation shown in Figure 2. Curves C, D, E, F, G, H represent periodicities of 68, 45, 25, 18, 14, and 8 months. Their sum in curve B roughly parallels the original curve A. These results indicate a real hope for long-range weather forecasting from solar-radiation observations.

spots due to the outrush of gases from within the sun and their consequent cooling by expansion as they reach elevations of diminished pressure. If in either of these ways local irregularities occur in the sun's surface brightness, the complete solar rotation which takes place in about four weeks must present these fluctuating intensities toward the earth in their turns, and so produce short-interval variations of the solar constant of radiation.

There is another variation of solar radiation, not periodic, but exceptionally interesting to theorists, as it throws light on the sun's inner nature. I refer to the difference of brightness between the edge and the center of the solar disk. Figure 6 illustrates this observation and shows how different is the phenomenon when viewed in differently colored rays. In the ultra-violet, the sun's center appears about three times as bright as its edge, while in the infra-red the edge

BRIGHTNESS DISTRIBUTION ALONG SUN'S DIAMETER
FOR DIFFERENT COLORS

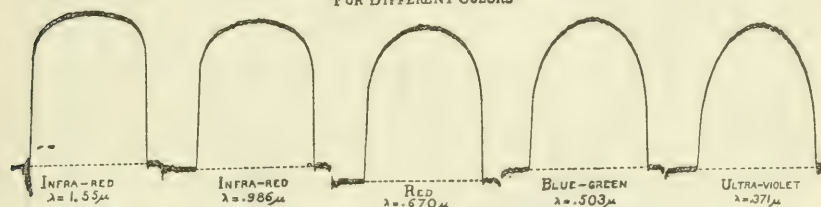


FIGURE 6.—Contrast of brightness between center and edge of the sun's disk as seen in different colors. From Smithsonian observations

is almost as bright as the center. A great deal of theoretical investigation has been based on exact measurements of these phenomena, which have been carried out in the years 1913 to 1920 by Smithsonian observers on Mount Wilson, Calif. This study is also associated with the determination of the distribution of brightness as between different wave lengths in the solar spectrum. Smithsonian observers have determined this as shown by Figure 7.

The study of the dependence of plant growth on radiation has lately been taken up by the new division of radiation and organisms at the Smithsonian Institution at Washington. In order to have a better control of radiation intensity and hours of exposure than clouds and night would permit if solar rays alone were employed, we use mainly electrical lamps of special construction; the results will be applicable to the understanding of plant growth under natural conditions.

The essence of the problem lies in this, that plants grow by taking in carbonic-acid gas from the air through millions of little mouths called stomata which dot the under surfaces of the leaves. But this feeding occurs only when certain rays found in sunlight and other sources shine upon the plants. The questions are: Which are the

effective rays? What differences are created in plant growth when the rays are changed either in color, in intensity, or in time of exposure per day? What are the chemical processes which go on in the laboratories of the plant leaves by which cellulose, sugars, odoriferous materials, fruit and nut substances, poisons, and the host of organic chemicals which plants produce are built up? Finally, how does radiation cause plants to bend in those interesting ways illustrated by the sunflower and nasturtium, and by the twining stalks of the beans and peas?

All of these questions are being studied at the Smithsonian Institution. The investigation is still young, so that little as yet has been published. Plate 1 and Figure 8, however, give some idea of the

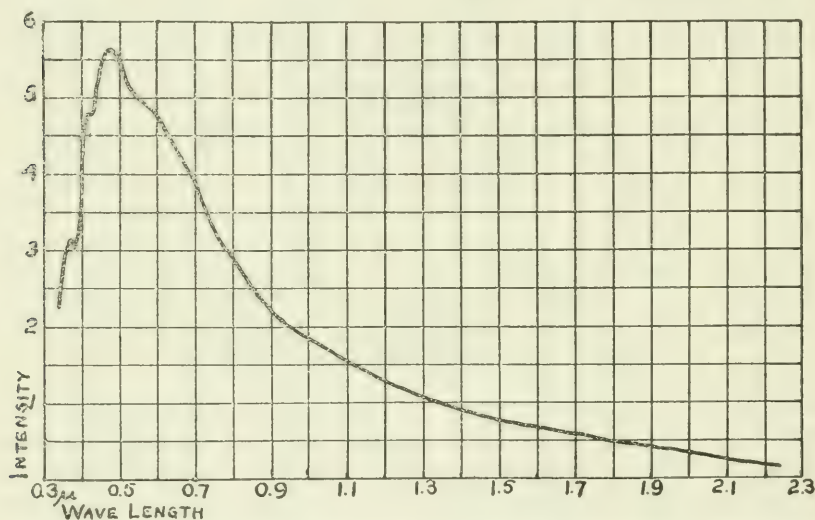


FIGURE 7.—Wave length and intensity in the solar spectrum. Smithsonian observations

ingenious apparatus and interesting work which have been developed already under the direction of Dr. F. S. Brackett. I will but mention the phototropic experiments in which a little oat sprout is being used as an indicator. It is situated between two lights of different colors, whose intensities may be graduated until the oat sprout grows vertically. Then, of course, the two lights are equal in their tendencies to produce bending. It is found that green is one thousand times more active than yellow, and blue thirty times more active than green to produce bending. Red and infra-red are like darkness, having no bending influence at all.

Another very promising line of investigation is that illustrated in Figure 8. Pure organic chemicals such as benzene, chlorobenzene, and others of greater and greater complexity are introduced in a spectroscope between the source of light and the recording thermopile

which automatically measures the spectrum energy. Absorption effects are produced on the infra-red rays. These effects are found to be characteristic for each chemical studied. In this way we are building up a system of organic chemical analysis, whereby chemical structure can be determined without making combustions. It is yet uncertain how powerful this method will eventually prove, but we hope it will throw much light on the abstruse reactions of plant growth under the influence of radiation.

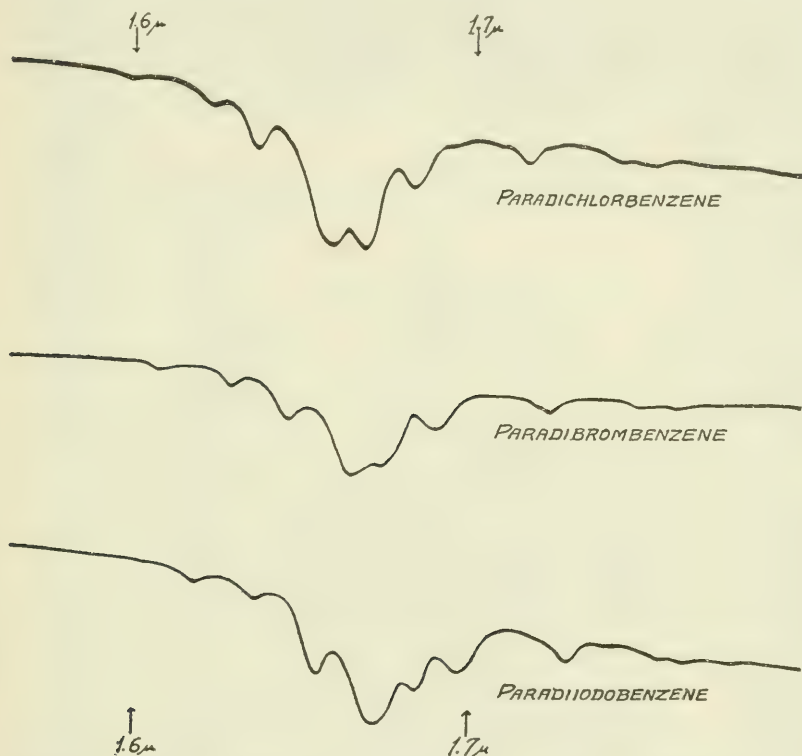


FIGURE 8.—Absorption spectra of benzene derivatives. Observed under the direction of Dr. F. S. Brackett, Smithsonian Institution

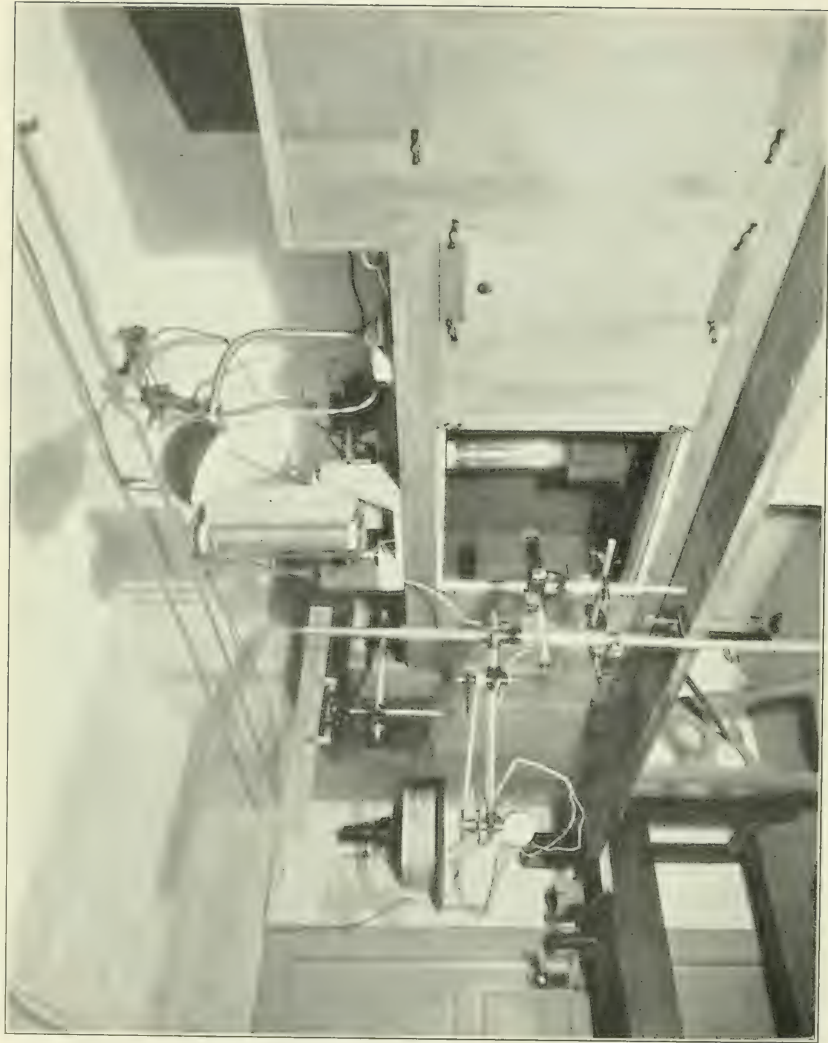
Plate 2 shows an experimental cooking plant which I erected at the Smithsonian station on Mount Wilson. Sun rays falling upon the great concave cylindric mirror, 7 by 12 feet in surface, and moved by clockwork to follow the sun, are reflected upon a blackened brass tube incased by a vacuum-glass jacket. Within the tube, which lies parallel to the earth's axis, is high-test engine cylinder oil. It grows hot, expands, and rises up into a reservoir containing about 60 gallons of oil. Two ovens for cooking are inserted in this reservoir of hot oil. A return tube from its bottom completes the circulatory system, bringing cooler oil to be heated by the mirror. For

weeks at a time on Mount Wilson, the ovens remained hot enough to bake bread both day and night. All kinds of cooking except frying and broiling are readily done with this solar cooker. The kitchen where food is prepared remains cool, and the housewife has a delightful view of the mountains as she steps out to place it in the ovens. The apparatus is too costly to be anything but a luxury.

The most successful solar power installation thus far made was located near Cairo in Egypt, and was used to pump water from the Nile for irrigation. A description of it is given in the Smithsonian Report for 1915. The principle is the same as that just illustrated in the solar cooker, but vacuum jackets were not introduced to enhance the heating.



PLANTS GROWING UNDER CONTROLLED LIGHT, HUMIDITY, AND TEMPERATURE,
SMITHSONIAN INSTITUTION



MEASURING PHOTOTROPIC BENDING OF OAT SPROUT, SMITHSONIAN INSTITUTION



ABBOT'S SOLAR COOKER ON MOUNT WILSON, CALIF.

VARIABLE STARS ¹

By DR. L. V. ROBINSON

Astronomer, Harvard College Observatory

The layman who has casually observed that the Big Dipper is always a dipper regardless of its position in the sky may also have noticed that all the stars appear to keep the same positions relative to one another. In general, the only exceptions are the planets. The layman, from somewhat hurried glances, may also be inclined to think that all the stars remain unchanged in brightness. If he could observe the stars a few thousand years hence, however, he would be convinced that "the stars do move," and a few days or weeks of continuous observation would also show changes in brightness of many of the brighter stars. The sun shares the motions of the other stars; in fact, it is dragging our little earth through space with a velocity of 12 miles per second relative to the other stars; but we move at a very slow rate compared with some of the suns, which are so far away in space that we call them stars.

The reason why the stars do not appear to move is that they are so exceedingly far away. Even the nearest is 275,000 times as far away as the sun is from us (that is $275,000 \times 92,900,000$ miles), and light from this star does not reach us until it has been on its journey four and one-third years. Light from the sun reaches us after a short journey of only eight minutes. By the way of contrast, it is said that the sensation of a burn travels so slowly relative to the speed of light, that an infant with an arm long enough to reach the sun would live his allotted time of three score and ten years and die in ripe old age before learning that his fingers had been burned.

But what of the brightness of all these far-away suns? By actually measuring their distances, astronomers can compare the brightness of each one with that of the sun. The intrinsically brightest star now known is one that is apparently associated with the great Magellanic Clouds of the southern sky. At maximum brightness this star, S Doradus, is half a million times as bright as our sun and, according to the theory of relativity in which mass and light

¹ Reprinted by permission, with author's alterations, from *The Scientific Monthly*, vol. 34, pp. 343-350, April, 1932.

energy are interchangeable, the light radiated in one second weighs more than 2,000,000,000,000 tons. It represents one class of stars known as "variables," on account of their variation in brightness. Among the variables, S Doradus is probably related to the subclass which the astronomer calls novae.

Within the earliest records of man the first star observed to vary in brightness was indeed a nova in the constellation Scorpius and was discovered by the Greek astronomer, Hipparchus, 134 years before Christ. This star, which appeared very suddenly as a dazzling bright object where one had not before been seen, aroused the curiosity of Hipparchus and undoubtedly prompted him to compile the first catalogue of star positions, by reference to which the appearance of any new star, or the disappearance of any of those which he had already observed and catalogued, could be established.

The outstanding peculiarity of novae is that they manifest a sudden outburst in brightness and then gradually fade away, becoming invisible to the unaided eye after a few weeks. The second known star of this kind, a nova in Cassiopeia, was observed first by Tycho Brahe, a Danish astronomer, in 1572. When Tycho first saw it, this star was among the very brightest in the sky; within a few days it grew still brighter so that it could be seen even in daytime without the use of a telescope. When the planet Venus is at its brightest, it is possible to observe it in the daytime, provided we know in what part of the sky to look, but Tycho's star is said to have been even brighter, notwithstanding the fact that Venus approaches us as closely as 26,000,000 miles, whereas most novae are probably hundreds of millions of times as distant.

In recent years a more careful watch has been kept over the stars; in fact at Harvard, the whole sky is photographed many times in the course of a year's work. Also more people know the constellations and recognize very quickly the presence of any new bright star where previously none had appeared. As a result, known examples of novae have increased fairly rapidly in recent years. The brightest of the recent ones appeared in 1918 in the constellation of Aquila. In less than a week the normal brightness of this star increased nearly 70,000 times, and on June 8 it was exceeded in brightness by only one other star, Sirius.

Aside from the telescope, no instrument has been more useful to the astronomer than the spectroscope. In its simplest form the spectroscope is nothing more than a finely polished glass prism through which light from a star, or from any other source, is allowed to pass. In passing through the prism the blue rays are always bent more than the red, depending upon wave length, so that ordinary "white light" is separated into all the colors of the rainbow.

These colors projected on a screen back of the prism constitute a "spectrum" whose general structure depends upon the nature and the source of the incident light. In the case of ordinary starlight, where a cooler atmosphere surrounds the source, very narrow widths of light are apparently missing, thus giving rise to a dark-line spectrum, the relative positions of the lines depending upon the chemical elements and conditions of temperature and pressure in the source of light, thereby revealing important data on the stars and their atmospheres. It may also happen that all the spectral lines may be shifted toward the red or toward the violet end of the spectrum. Wave lengths from a given source are all shortened by motion toward the observer for the reason that the observer meets more waves per second than he would were he at rest relative to the source. This shortening of wave lengths indicating motion toward the observer accounts for the shift toward the violet end of the spectrum constituting the shorter wave lengths, and conversely a shift toward the red indicates motion away from the observer. Thus the observer is able to distinguish motions of the stars in the line of sight and to measure their velocities. This fact alone is a very important one in the study of variable stars and of the very close double star systems, called spectroscopic binaries.

From the spectra of novae the astronomer is able to detect the presence of gases rushing out from these stars with velocities as high as 1,200 miles per second. We are led to conclude, therefore, that the great increase in brightness of these stars is due partly to an increase in diameter caused by some kind of explosion. The frequency of these explosions suggests to us that possibly similar disturbances occur within every star, at least once in its lifetime. If so, what warning are we to have of the approach of an explosion of the sun? The sun is only a star among the 30,000 million others which astronomers believe are in our Milky Way system. Why then should it be the exception to the other stars? What if it should explode? We frequently see spots on the sun large enough to hold our little earth; we might therefore be justified in concluding that in a solar conflagration, similar to that which apparently takes place in a nova, the earth would disappear almost instantaneously.

As a representative of a second type of variable there is none better than Mira, the Wonderful, a star in the constellation of Cetus, which changes continuously in brightness, reaching a maximum and minimum periodically. The variations of Mira were first seen by the Dutch astronomer, Fabricius, in 1596; a star of moderate brightness appeared where one had not previously been seen. In a few weeks it had faded away and it was therefore thought to be a nova, until the year 1638 when it was seen again by another Dutch astron-

omer, Holwarda, who observed that it appeared and disappeared within a period of about 11 months. To the telescopic observer this star does not actually disappear, but when it is faintest it gives only about one per cent of the visual light which it gives when it is brightest. Since the time of Fabricius and Holwarda, the number of recognized stars of this type has increased, especially during the last few years, until now our catalogues contain about two thousand other examples.

All of the stars of this type are more or less red and appear to be among the coolest stars in the sky. In their outer layers at least, they apparently vary in temperature and in color as well as in luminosity, but the highest temperature exhibited by a variable of this type never exceeds that of a very hot furnace, while many of the blue stars show temperatures ten times as high. Among the giant stars, in general, low temperatures and large diameters are very closely correlated and are thought to be characteristic of the earliest stages of a star's development. The enormous size of Mira is illustrative, probably, of all long-period variable stars. If the sun were placed at the center, inside the body of Mira, and the distance (92,900,000 miles) between the sun and its companion the earth were unchanged, the earth would be several million miles below the surface of the star. Not only the earth, but Mars, which is 50 per cent farther away from the sun than the earth, would be beneath the surface of this giant star.

At the level which we call the surface of Mira, the constituent gases are much rarer than those composing the atmosphere of the earth, 50 miles above its surface; in fact, they are in a rarer condition than can be duplicated by exhausting the air of a vessel with the best air-pump yet constructed. The rarity of the gases at the surface of this star is due to the smallness of the gravitational pull which varies inversely as the square of the diameter. A man weighing 200 pounds on the earth would weigh less than 4 ounces at the surface of Mira, were it possible to weigh him with spring balances in each case. On the small dwarf star circling about Sirius, by way of further contrast, this man weighed by the same method would weigh no less than 3,000 tons, whereas on our sun he would weigh only 5,500 pounds, or somewhat less than 3 tons!

In many ways the class of variable stars to which Mira belongs, ordinarily called long-period variables, is closely related to another type known to astronomers as Cepheid variables. The earliest observed type of this class is Delta Cephei, discovered by Goodricke in 1784. These stars are not so red as the long-period variables, and their periods of variation extend from a few hours to about 70 days, whereas the periods of long-period variables range from about 100

days to about 2 years. Furthermore, the range of variation in brightness is, in general, much less in the case of Cepheids than in some Mira-type stars where the brightness at maximum is 50,000 times that at minimum. Astronomers believe, however, that Cepheids are related to long-period variables because a correlation between redness and period, which has been noted among Cepheids, can also be extended to the long-period variables. The Cepheid variables and those of long period are generally believed to be pulsating—that is, both classes may owe their changes in brightness partly or wholly to periodic expansions and contractions of the gases composing them. There are some astronomers, however, who believe that the variations in luminosity of the Cepheids are due to rotation and to their peculiar shapes. It is claimed that they are pear-shaped and eventually break up into two stars. Each theory has its objections, and much more work remains to be done before the matter can be considered as settled. Figure 1 illustrates how a Cepheid may divide into a binary system.

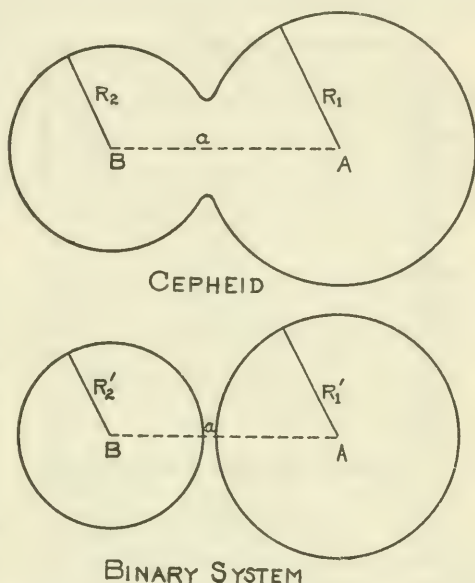


FIGURE 1.—The transition of a binary system from a Cepheid

According to the Jeans theory, the transition from the Cepheid stage may be the result of contraction. Thus R_1 and R_2 decrease to R'_1 and R'_2 , respectively. In the first case the sum of R_1 and R_2 is greater than the distance from A to B , and in the second it is less.

The question, "What are Cepheid variables?" is hardly more interesting than the question, "What are they good for, astronomically?" In fact, solving the latter question has served astronomical advancement to a far greater extent probably than any other research which has been pursued in many years. It happens that in certain star clouds and clusters many Cepheid variables are found. In studying the variables in the Magellanic Clouds, Miss Leavitt, at Harvard, discovered that a relation exists between the periods of variation and the apparent brightness of these stars: The longer the period, the brighter is the star—the so-called period-luminosity relation. Since all the stars in the Magellanic Clouds are at very nearly the same distance from the earth, it can also be demon-

strated that a relation exists between period and *actual* or *absolute* brightness. In other words, if we know the actual brightness of one Cepheid variable, then we can compute the distance of any other star of this type, once its period and apparent brightness are known. This is equivalent to saying that we must know the "zero point" of the period-luminosity relation in order to use it effectively. The zero point is determined from the apparent motions of the stars, since those nearest to us appear to move the fastest; hence the distance and therefore the brightness of an average star may be known.

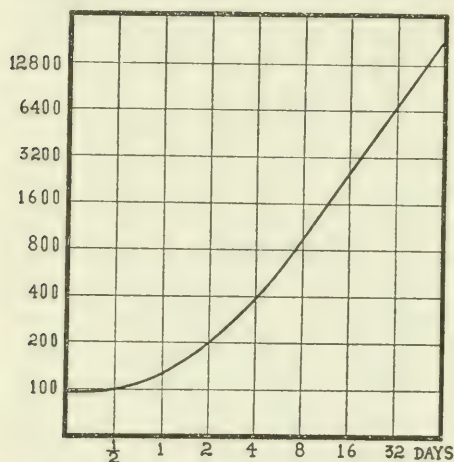


FIGURE 2.—The period-luminosity relation

Horizontal axis is period in days, and vertical axis is intrinsic luminosity in terms of sun's brightness. The zero point is fixed when it is known, for example, that the average Cepheid with a period of two days is 200 times as bright as the sun.

The enormous brightness of Cepheids favors their use as yardsticks in measuring the size of the universe. The faintest of these stars, the so-called cluster-type Cepheids, are intrinsically about a hundred times as bright as our sun; consequently one of these stars can be seen when it is ten times as far away as a star of the brightness of our sun. The brightest representatives of the Cepheid class, which are about 10,000 times the brightness of the sun, can be seen at vastly greater distances. The huge 100-inch Mount Wilson telescope shows stars which give less than one-millionth the amount of light of the faintest stars visible to the unaided eye, and consequently with it one sees stars over a thousand times more distant. In fact, Cepheids on the outskirts of our universe and among the great star clouds of the Milky Way system are visible in the Mount Wilson telescope. The farther cluster of stars measured by Shapley

This important relation between brightness and period is illustrated in Figure 2.

The period-luminosity relation proved to be the key that unlocked one of the secrets of the universe. The key was immediately seized by a young astronomer at Mount Wilson Observatory, and soon we knew the distances of all the far-away clouds in which the telescope revealed the presence of Cepheid variables whose periods could be determined. This young astronomer was Dr. Harlow Shapley, the present director of Harvard College Observatory.

was so far away that light received from the members was over 200,000 years old; or, the cluster is said to be 200,000 light years distant. In the opposite direction, clusters were observed at distances of the order of 100,000 light years. For the first time in the history of astronomy investigators could say definitely that the universe had been sounded, and that its diameter was so large that 300,000 years were required for light to traverse it. Yet only a short time later, Hubble, at Mount Wilson, began to count variable stars, such as Cepheids and novae, by the dozens in the Andromeda nebula, identifying it as a great collection of stars, sometimes called an "Island Universe." Thus he was able to measure distances more than three times as large as those previously determined. From this great collection of stars, which to the unaided eye appears as a hazy spot in the sky, nearly one million years is required for light to reach us. Some idea of the distance of this far-away cloud of stars can be gained when it is recalled that light from the sun reaches us in only eight minutes (fig. 3).

The variable stars hitherto discussed are all intrinsically variable and in this way differ from the class of objects represented by Algol and Beta Lyrae. Algol, or Beta Persei, may have been recognized as a variable by the Arabs, since it was called by them *al Ghul*, or the demon, possibly on account of its apparent capricious drops in luminosity. The first historical evidence of its variability, however, seems to rest with Montanari, who noticed its variability in 1669, without attempting any careful study of the star. It was observed again in 1782 by a young Englishman, John Goodricke, a deaf mute, who not only determined its period of variation but also correctly suggested the cause. Beta Lyrae was discovered two years later by Pigot, a friend of Goodricke. Each of the two systems just mentioned owes its variability to periodic eclipses by the component star. In the case of Algol, one of the components is faint relative to the other, which is called the primary, whereas in the case of Beta Lyrae both components are approximately of the same brightness and relatively much closer together than the components of Algol. In fact, for many systems of the Beta Lyrae type, the components, which are generally of the same brightness, are very nearly in actual contact. The range of periods of eclipsing stars, including those of the Algol and Beta Lyrae types, agrees very closely with the range of periods of Cepheids. The amount of change in brightness is also about equal to that of Cepheids. For eclipsing stars, the amount of change depends upon the relative brightness of the two components of the system and upon the orientation of the plane in which they revolve to the line of sight.

It is clear that eclipsing stars constitute a very special selection among double stars: They are those systems where one star passes in front of the other and cuts off a part or all of its light, in much the same way that the moon cuts off the light of the sun when a solar



FIGURE 3.—Distribution of globular clusters

Plane of paper is plane of milky way; large concentric circles represent distances from sun (at center of diagram), the unit being 25,000 light-years; the center of the milky way system is represented by a cross. Small circles represent globular clusters; farthest cluster is too far away to appear on the diagram.

eclipse occurs. They constitute only a part of those close doubles which to the unaided eye or in the telescope appear as single stars. There are other systems whose components revolve in planes so oriented relative to the line of sight that no eclipse can occur. These are the spectroscopic binaries, the duplicity of which is revealed from

analyses of the light received from them by means of the spectroscope. Still more complicated are those systems which the telescope shows as double or multiple, where one or more components of the visual system are in reality spectroscopic binaries. Thus, the astronomer is able to discover that what appears as a single star to the unaided eye is in some cases a complex system of stars revolving about their centers of gravity, with periods from a fraction of a day to hundreds or even thousands of years. Such a system is Castor, the fainter member of Gemini, the twins. In this instance the telescope shows two bright stars exceedingly close together where the eye only sees what appears to be a single star. These two stars revolve about each other with a period of about 350 years. The third and fainter member of this same system is found a little farther away revolving about the common center of gravity probably with a period of more than a thousand years. Each of these three stars is a spectroscopic binary, so that in reality we have six stars belonging to a system where the unaided eye would see a single bright star. It is estimated that of all the stars in the sky, one of every three or four is a double or a multiple system. This is only one bit of evidence suggesting gregarious tendencies among the stars.

Astronomers believe that the distinction between visual telescopic double stars and the class of eclipsing and spectroscopic binaries is more real than apparent. Members of the former class have periods measured in years while those of the latter class, with a few exceptions, have their periods restricted below 100 days. But why the difference? This is one of the questions of modern astronomy. Unless the universe is very much older than we believe it to be, near approaches and captures are not frequent enough to account for the large number of visual and telescopic doubles even if, under such circumstances, captures are possible. Serious doubts indeed arise if we assume that capture of one star by another may result at all from near approach. Probably the best suggestion is that visual doubles result from condensations about two separate nuclei in an early nebular stage of evolution. The revolution of one star about another, with reference to spectroscopic and eclipsing binaries as well as to visual doubles, is not more strange than the much more general fact now established by modern astronomy, that all the stars of the Milky Way system are revolving about their common center of gravity. To carry this idea further, it must also be concluded that visual and telescopic binaries were formed at a time when the Milky Way system was yet young and when all the stars were closer together than at present. At least we now see no evidence of the formation of such systems,

The question of the origin of eclipsing and spectroscopic binaries, according to some astronomers, has a close connection with the question of interrelationships of the different classes of variable stars: Jeans has proposed the theory that all variable stars are rotating and that when the period of rotation becomes sufficiently rapid, as in the case of the short-period Cepheids, the stars can no longer hold themselves together—a hypothesis known as the fission theory. If then a Cepheid is the parent of a binary system, how are we to prove it? Astronomical questions rarely lend themselves to direct proof, unfortunately, but any clue serves as a valuable bit of evidence either for or against a theory in question. We have evidence for extending the connecting links between long-period and Cepheid variables to eclipsing and spectroscopic binaries as well. We may mention: (1) There are spectroscopic evidences indicating rotation of Cepheids about their respective centers of gravity; (2) the mean densities of Cepheids are approximately what we should expect of two embryo stars in actual contact; (3) the mean radii of Cepheids compare favorably with the separation of the components of short-period binary systems; (4) slight evidences of correlations of colors and brightnesses of short-period binaries with Cepheids are to be found; (5) the agreement of periods is as good as can be expected; and (6) the space distributions of the two classes of objects compare favorably.

Of these arguments the first must carry considerable weight. By means of the spectroscope it has been found that motion of the star or of some part of it toward the observer is greatest at maximum light or shortly thereafter. It is also believed from the evidences now available that the star is hottest at maximum light, approximately. Both can not be true of a pulsating star; mathematical analysis involving considerations of luminosity, radius, and temperature shows that the star should be neither expanding nor contracting, or in other words, it shows that the velocity in the line of sight should be zero at maximum light, provided that the temperature is hottest at about this time, as is generally believed. On the other hand, however, either of the two systems in Figure 1 should show greatest velocity of approach at maximum light if maximum light is to be associated with maximum visible surface. To agree with observations, the part of the Cepheid from which most of the light apparently comes at this moment should also be hottest, and consequently a very unequal temperature distribution over its surface is demanded on the basis of the fission theory. It is evident therefore, that although most of the above six arguments are necessary conditions to substantiate a fission theory such as that of Jeans, they are not sufficient; they prove nothing.

Arguments against the theory are also serious and difficult to meet. About the only alternative left for the fission theory proponent is to ask: What *are* the ancestors of this class of binary stars? Equally well may one ask the same question with regard to all double star systems. For the visual and telescopic doubles, however, the above conditions are neither necessary nor sufficient, and by no one is any relationship claimed between these stars and any class of variables.

In our own galactic system the total number of known variable stars given by the 1932 edition of Prager's catalogue is 5,461, about a large percentage of which nothing is known. A relatively large percentage of the remainder belongs to classes of irregular or semi-regular stars which may be intermediate between the various classes of periodic variables. We know practically nothing about these stars, since they demand series of observations more continuous than those now available. It is quite possible also that continuous series of observations made on all classes of variables would shed much light on the peculiarities and the causes of their variations which have hitherto escaped our attention.

Not only the professional astronomer but the amateur, likewise, can assist in answering astronomical questions. The part of the amateur astronomer is most strikingly manifested by the great work of the American Association of Variable Star Observers, composed of about 350 members working in this country and abroad, who in the course of a year report more than 25,000 observations on variable stars to its recorder, Mr. Leon Campbell, of Harvard College Observatory. By this organization more than a third of a million observations have been made on 500 variable stars, mostly of long period, and for the peculiar variable SS Cygni not a single maximum brightness during the last 35 years has escaped their notice. Besides this enormous program, a huge amount of variable star work is done at Harvard College Observatory by temporary employees who have other lines of activity and who do not claim to be professional astronomers. The field is a large one, and thus far we believe that we have done little more than penetrate the surfaces of the associated problems.

THE MASTER KEY OF SCIENCE: REVEALING THE UNIVERSE THROUGH THE SPECTROSCOPE ¹

By HENRY NORRIS RUSSELL

Professor of Astronomy, Princeton University

[With 2 plates]

The great French philosopher of the last century, Auguste Comte, was an exceedingly well-informed and versatile man, but it was he who once remarked: "There are some things of which the human race must forever remain in ignorance; for example, the chemical composition of the heavenly bodies." To Comte and the other intelligent men of his time, this problem seemed hopelessly insoluble; there was no way of attacking it.

Of course this statement sounds ridiculous to us now. It became ridiculous because man's dream came true of a master key that would unlock many doors, one after another, and so open up many new realms of knowledge.

That master key was the spectroscope. No sooner was it discovered than the composition of the heavenly bodies, previously unknowable, became an open book. With its use, many of the familiar chemical elements were identified in the sun, and not long after, in the stars. Later work has extended the number of elements identified in the sun to 60, and spectroscopic study has shown that the atmosphere of Mars contains oxygen and water vapor, while that of Venus shows no signs of them.

All the stronger lines in the spectra of the sun and stars and a host of the weaker ones have been identified. It has been demonstrated that the same atoms are present on earth that are also present in the remotest nebulae, in the relatively cold tail of a comet, and in the intensely heated surface of a white star. By showing these things, the spectroscope has given the most impressive of all proofs of the unity of nature.

This achievement has been described in poetry, as it should be, by Edmund Clarence Stedman, in one of his more philosophical

¹An address delivered at the inauguration of the spectroscopic laboratories of the Massachusetts Institute of Technology, Feb. 25, 1932. Reprinted by permission from Technology Review, April, 1932.

poems "Corda Concordia." The stanza in which this is done is such good science, as well as such good poetry, that I would like to quote it:

White orbs like angels pass
Before the triple glass,
That men may scan the record of each flame—
Of spectral line and line
The legendry divine—
Finding their mould the same, and aye the same,
The atoms that we knew before
Of which ourselves are made—dust, and no more.

It is more than 200 years since Newton, passing his beam of light in a darkened room through a prism, saw the rainbow-colored streak of light upon the wall as the rays of different color were refracted in different amount by the prism, and so was led to realize the composite nature of white light. Unfortunately, Newton took his light through a small round hole and he took it from the large round sun; consequently, even if the sun had been all one color, the image that he would have had thrown on the wall would have been like the image that he got when it came through a pinhole in the window shade. If only he had had the wit to set up a narrow slit so that the image would have been sharp and not round, the master key might have been discovered.

Just after the first half of the nineteenth century was over, Kirchhoff and Bunsen made that simple but fundamental mechanical change. Really this master key was found in a narrow slit—simply in letting your light into this prismatic instrument through a slit so narrow that you obtained a sharply defined image. As soon as that was done, as soon as they took the light through a narrow slit into their prism, with an eyepiece to look at it and a couple of other lenses to make the light go in parallel rays through the prism—the new doors were opened and the new worlds free to conquer.

The next necessary advancement was the development of a more delicate method of spectrum analysis. This came with Rowland, the great Johns Hopkins physicist in the nineties. He developed an engine for ruling diffraction gratings, the device that is used for breaking light up into its components. The best of Rowland's gratings are the joy, the envy, and the despair of the investigators to-day—the joy of the man who has one, the envy of his colleagues, and the despair of the man who tries to make one as good. Rowland devoted years to the study of the solar spectrum and reported and recorded in it the position of 20,000 lines, each one carrying its own story of some substance in the sun. When Rowland was through his work, 36 of the chemical elements had been identified in the sun. Since that day, of course, a number more have been added because

plates have been developed which are sensitive to the red end of the spectrum, and Rowland had no such plates available. Partly for that reason, and partly because some substances are now available of which Rowland could not get specimens, 60 chemical elements have now been identified in the sun—most of them with certainty.

In the stars, we can not observe such immense detail as we can in the sun, although the big spectroscopes that are now being attached to the great refractors such as the Mount Wilson 100-inch telescope give us an amazing amount of information, and dozens of different chemical elements have been definitely identified in the stars.

The minute shift in the position of the lines due to motions of approach or recession has enabled us to detect and measure the rotation of the sun and the planets, to prove that Saturn's rings are not solid, but composed of myriads of tiny satellites, and to get one of the most accurate determinations of the sun's distance. Applied to the stars, it has determined the sun's motion among them, the distances of hundreds of individual stars, and the average for thousands more; has revealed hundreds of double stars too close to be resolved by the telescope, and determined the masses and even the diameters of some of them; and has disclosed those amazingly rapid motions of the remote nebulae—some as high as 15,000 miles a second—which point the way to new conceptions of the nature, the past, and the future of the material universe. Spectroscopic tests have shown that the nebulae are of two kinds, one consisting of masses of luminous gas; the others, giving light like stars, must themselves be great clusters of stars at gigantic distances.

If the spectroscope has thus proved so profitable to the astronomer, what has it accomplished for scientists in other fields? The chemist owes to spectroscopy the discovery of at least 10 of the elements, some by optical methods, others more recently by the aid of X rays. Among these is helium, which was detected in the sun and its nature as a light gas correctly interpreted more than 20 years before it was "run to earth."

The classical physicist finds in the spectroscopic data his most precise standards of length, and some of his more accurate methods of measurement. My friend, Doctor Meggers, of the Bureau of Standards, and his associates have developed very practical spectroscopy recently. Suppose, for example, you have some fusible plugs that are used in our overhead sprinkler systems. They are made of a fusible alloy which will be greatly damaged if it has any more than the most minute quantity of iron in it. To find this out by chemical analysis is a slow and tedious process; but you can take one of these plugs and test it with the spectroscope, and if the strong lines of iron show up, you know there is iron there. Comparative

tests with materials of different composition give you an idea of the safe limits. Thus, with the spectroscope you can test these alloys in a minute part of the time that chemical analysis requires.

But it is in the realm of atomic physics that spectroscopy has played its greatest rôle. Fifty years ago, Lockyer, from a study of the spectra of electric arcs and sparks, and of the stars, concluded that, in the spark and in the hotter stars, ordinary atoms are decomposed into products which give different spectral lines. This bold generalization was fully justified 40 years afterward, by the development of the theory of ionization.

About 40 years ago, series of lines were detected in many of the simpler spectra, and found to be representable by formulae in which the "Rydberg constant," common to all spectra, appeared. Here was evidence of some uniform feature in the constitution of the different atoms. The Zeeman effect, according to which a spectral line emitted by a source placed in a strong magnetic field is split up into polarized components, again showed features common to different atoms, and suggesting the presence within them of moving electrical charges. The Bohr-Rutherford theory of atomic structure—with electrons in orbital motion around a nucleus—was based very largely on these spectroscopic data. It accounted at once for the typical spectral series of hydrogen, and accurately predicted other series in the infra-red and ultra-violet. With simple modifications, it explained the more complicated system of series in the spectra of the alkalis. The multiple character of the terms of the series was later interpreted as a result of the spin of the electron—thus increasing the "astronomical" resemblance of the atom-model; while the appearance of numerous terms in the more complex spectra was accounted for by differently quantized inclinations of the electron orbits. The complex multiplets of lines found in the spectra were thus fully explained. In its final form (due to Hund) this theory has been brilliantly successful in elucidating the structure of atoms and interpreting and even predicting the details of their spectra. Work in this field has been very active, and only the most complex spectra (rare earths and some heavy metals) and those of a few very rare elements remain to be deciphered.

In the case of molecules, changes in the states of oscillation and rotation of the nuclei, as well as in the electronic states, are possible, and the spectra are much more intricate, consisting of complex bands comprised of closely packed lines. Those of diatomic molecules are now well understood—with important gains in our knowledge of molecular structure and the nature of chemical "affinity"—and the still more intricate polyatomic molecules show signs of yielding. Different isotopes of the same element, when present in compounds, often

give widely separated bands. From these, new isotopes of oxygen, nitrogen, and carbon have been discovered, and the ratio of the masses of the different atoms determined with extreme precision. In atomic spectra, the isotope effect is extremely small, except for hydrogen—where it has recently permitted the identification of an isotope of double weight.

Fine structure in the lines of heavier atoms arises partly from the presence of isotopes and partly from some sort of "spin" within the atomic nucleus; and its study affords a promising approach to the problem of nuclear structure.

While all this was going on, X rays were also found to contain monochromatic radiations, observable by using the atoms in a crystal as a diffraction grating. These spectra have given us information about the interior of atoms, comparable with that which optical spectra furnish concerning the exterior. They are much simpler than the latter, and now furnish the chemist with his most delicate test for the detection of new elements. Incidentally, they make it certain that except for the few well-recognized gaps, no elements lighter than uranium remain to be discovered.

Working in the opposite direction, X-ray spectroscopy opens the door to another untrodden realm—the exact study of the arrangement of atoms in crystals, which can now be specified in minute detail.

All through these triumphs ran a discordant note. Certain numerical relations—notably in the Zeeman effect—though exact, differed systematically from those predicted by the orbit theory, and every calculation based on the relative positions of electrons in these orbits led to a wrong answer. This discrepancy has vanished since the orbital picture of the atom was replaced by the difficultly visualizable wave-mechanics or the wholly unpicturable matrix theory. When a modern lecturer tries to draw an atom on the blackboard, he uses not chalk, but an eraser, and constructs a smudge illustrating the relative probability of finding a unit charge in different regions. But as a means of calculation—interpreting and, on occasion, predicting the results of precise observation—the new theory advances from conquest to conquest.

The ramifications of these new ideas throughout the range of molecular and atomic physics are too numerous to mention. To take but one instance at random, the magnetic susceptibilities of solutions of salts of the rare earths may be fully explained by the theory of spectral structure—even though the spectra of the trebly ionized atoms (upon which these depend) have not yet been observed.

There is probably no field in which the new spectroscopy has been of more aid than in astrophysics. The recognition that Lockyer's

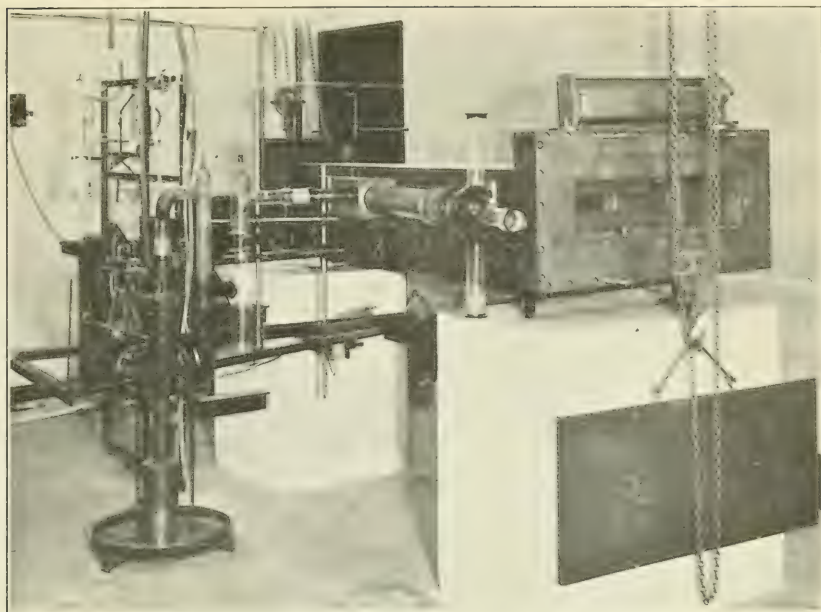
enhanced lines are produced by ionized atoms, and the general application of the laws of ionization to stellar atmospheres have transformed our whole viewpoint. We know now that the disappearance of the lines of the metals from the hot stars means only that they have been so highly ionized that they no longer give lines in the observable region, and that the lines of the permanent gases, and the nonmetals generally, are weak or absent in the cooler stars because their atoms are not highly enough excited to be able to absorb the observable lines. From measures of line width, and also by study of multiplets, the actual number of atoms which produce a given spectral line may be estimated, and an approximate quantitative analysis made of the atmospheres of the sun and stars. The results indicate a remarkable similarity of composition, despite the great differences in the spectra of hot and cool stars. The relative abundance of the elements is similar to that in the earth's crust or in meteorites, with one noteworthy exception. Hydrogen—a minor constituent here—is overwhelmingly predominant in the stars. (The excess very likely escaped during the formation of our planet.) Both the temperature and pressure of a star's atmosphere may be found from the intensities of the spectral lines. The former agree with the values deduced from the colors of starlight; the latter are surprisingly small, and indicate that the atmospheres are of exceedingly low density. The whole atmosphere of the sun, brought to standard temperature and pressure, would make a layer of gas less than a hundred feet thick, of which the metallic vapors form about 1 per cent.

A similar conclusion was reached more than 40 years ago by Lockyer, by the simple process of comparing the sodium lines in the solar spectrum with those absorbed by the vapor present in a Bunsen flame. The sun's atmosphere, of course, is not sharply bounded at the bottom; it grows hazier owing to the increasing density of the free electrons and ions, and passes into the luminous photosphere. The principles upon which this increasing opacity can be calculated are essentially spectroscopic, and the data regarding the ionization and excitation potentials of atoms, which it requires, have been derived spectroscopically.

Two more applications may be mentioned—to matter in extreme states of condensation and rarefaction.

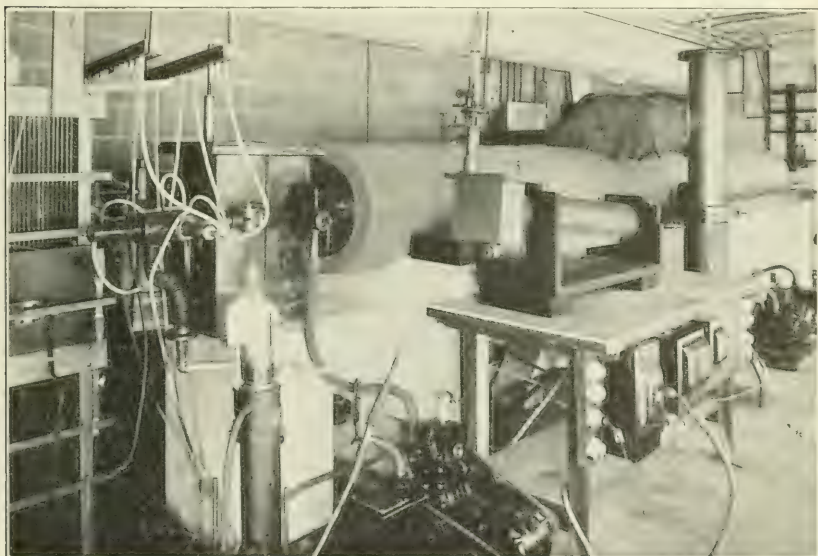
From the spectroscopic data regarding atoms it follows that, at very high temperatures, inside the stars, they will be completely ionized down to bare nuclei and electrons. Matter in this state should be exceedingly compressible, but not infinitely so—the limiting factor being the degeneracy of the gas (in the sense of the new quantum theory) at a density several hundred thousand times that of

water. The problematical white dwarf stars, like the companion of Sirius, show conclusive evidence of being in this state, while the shift toward the red of the lines in their spectra (coming from the outer atmosphere) affords an important confirmation of general relativity. At the other extreme, the gaseous nebulae—which from gravitational considerations must be of extreme tenuity—show spectral lines which were long a tantalizing problem. Modern spectroscopy revealed the existence of metastable atomic states, from which light-producing transitions would not occur unless the individual atoms were left undisturbed much longer than they would be except in an exceedingly rarefied gas. Bowen thus identified the nebular lines as “forbidden” lines of the sort produced by the most familiar elements, oxygen and nitrogen above all. The hypothetical unknown element nebulium thus very literally vanished into thin air.



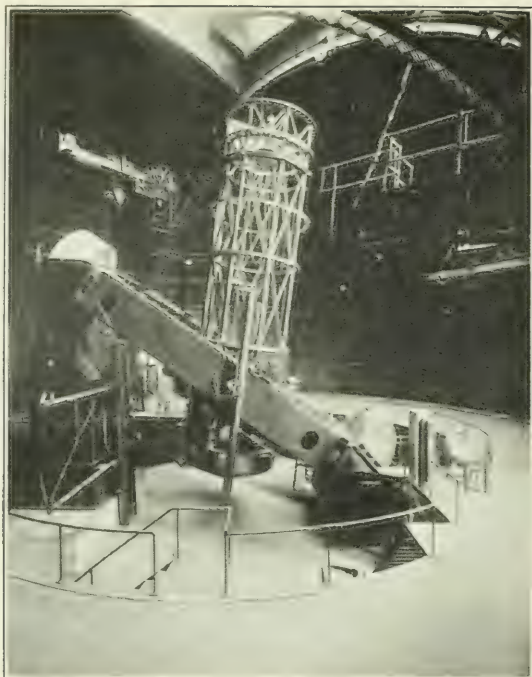
1. A VACUUM SPECTROGRAPH USED FOR STUDIES IN THE EXTREME ULTRA-VIOLET REGION OF LIGHT

It was developed from a design of Prof. Karl T. Compton, of Massachusetts Institute of Technology, with the assistance of Dr. Joseph C. Boyce, a research associate in the department of physics. It is in the spectroscopic laboratory at M. I. T., a "science wonderland," which "represents the heaviest artillery yet concentrated by science for assaulting the citadel of the atom."



2. THE GREAT 21-FOOT VACUUM SPECTROGRAPH AT M. I. T., THE LARGEST EVER BUILT

It was designed by Prof. George R. Harrison, director of the spectroscopic laboratory. When the cylinder is evacuated, the force exerted by the atmosphere on the outside is approximately 88 tons. The size of this huge spectroscope is indicated by comparing it with the one on the table which is of the size customarily used in this field of research.



1. THE GREAT HOOKER 100-INCH TELESCOPE AT MOUNT WILSON OBSERVATORY

It has been enormously valuable in spectroscopic research.



2. THE SPECTROHELIOGRAPH INVENTED BY GEORGE ELLERY HALE, 1890

THE DECLINE OF DETERMINISM¹

By SIR ARTHUR EDDINGTON, F. R. S.

Determinism has faded out of theoretical physics. Its exit has been commented on in various ways. Some writers are incredulous and can not be persuaded that determinism has really been eliminated. Some think that it is only a domestic change in physics, having no reactions on general philosophic thought. Some imagine that it is a justification for miracles. Some decide cynically to wait and see if determinism fades in again.

The rejection of determinism is in no sense an abdication of scientific method; indeed it has increased the power and precision of the mathematical analysis of observed phenomena. On the other hand I can not agree with those who belittle the general philosophical significance of the change. The withdrawal of physical science from an attitude it has adopted consistently for more than 200 years is not to be treated lightly; and it involves a reconsideration of our views with regard to one of the perplexing problems of our existence. In this address, I shall deal mainly with the physical universe, and say very little about mental determinism or free will. That might well be left to those who are more accustomed to arguing about such questions if only they could be awakened to the new situation which has arisen on the physical side. At present I can see little sign of such an awakening. Waking is a rude process; and if I sometimes shout it is because current literature resounds with the snores of those who are asleep.

DEFINITIONS OF DETERMINISM

Let us first be sure that we agree as to what is meant by determinism. I quote three definitions or descriptions for your consideration. The first is by a mathematician (Laplace):

We ought then to regard the present state of the universe as the effect of its antecedent state and the cause of the state that is to follow. An intelligence, who for a given instant should be acquainted with all the forces by which nature is animated and with the several positions of the entities composing it,

¹ Presidential address to the Mathematical Association, 1932. Reprinted, by permission, from the Mathematical Gazette, vol. 16, No. 218, May, 1932.

if further his intellect were vast enough to submit those data to analysis, would include in one and the same formula the movements of the largest bodies in the universe and those of the lightest atom. Nothing would be uncertain for him; the future as well as the past would be present to his eyes. The human mind in the perfection it has been able to give to astronomy affords a feeble outline of such an intelligence. * * * All its efforts in the search for truth tend to approximate without limit to the intelligence we have just imagined.

The second is by a philosopher (C. D. Broad) :

"Determinism" is the name given to the following doctrine. Let S be any substance, ψ any characteristic, and t any moment. Suppose that S is in fact in the state σ with respect to ψ at t . Then the compound supposition that everything else in the world should have been exactly as it in fact was, and that S should have been in one of the other two alternative states with respect to ψ is an impossible one. [The three alternative states (of which σ is one) are: To have the characteristic ψ , not to have it, and to be changing.]

The third is by a poet (Omar Khayyam) :

With Earth's first Clay They did the Last Man's knead,
And then of the Last Harvest sow'd the Seed:
Yea, the first Morning of Creation wrote
What the Last Dawn of Reckoning shall read.

I propose to take the poet's description as my standard. Perhaps you will think this is an odd choice; but there is no doubt that his words express what is in our minds when we refer to determinism. The other two definitions need to be scrutinized suspiciously; we are afraid there may be a catch in them. In saying that the physical universe as now pictured is not a universe in which "the first morning of creation wrote what the last dawn of reckoning shall read," we make it clear that the abandonment of determinism is no technical quibble but is to be understood in the most ordinary sense of the word.

It is important to notice that all three definitions introduce the time element. Determinism postulates not merely causes but pre-existing causes. Determinism means predetermination. Hence, in any argument about determinism, the dating of the alleged causes is an important matter; we must challenge them to produce their birth certificates.

Ten years ago practically every physicist of repute was, or believed himself to be, a determinist, at any rate so far as inorganic phenomena are concerned. He believed that he had come across a scheme of strictly causal law, and that it was the primary aim of science to fit as much of our experience as possible into such a scheme. The methods, definitions, and conceptions of physical science were so much bound up with this assumption of determinism that the limits (if any) of the scheme of causal law were looked upon as the ultimate limits of physical science.

To see the change that has occurred, we can consider a recent book which goes as deeply as anyone has yet penetrated into the fundamental structure of the physical universe, Dirac's *Quantum Mechanics*. I do not know whether Dirac is a determinist or not; quite possibly he believes as firmly as ever in the existence of a scheme of strict causal law. But the significant thing is that in this book he has no occasion to refer to it. In the fullest account of what has yet been ascertained as to the way things work, causal law is not mentioned.

This is a deliberate change in the aim of theoretical physics. If the older physicist had been asked why he thought that progress consisted in fitting more and more phenomena into a deterministic scheme, his most effective reply would have been "What else is there to do?" A book such as Dirac's supplies the answer. For the new aim has been extraordinarily fruitful, and phenomena which had hitherto baffled exact mathematical treatment are now calculated and the predictions are verified by experiment. We shall see presently that indeterministic law is as useful a basis for practical predictions as deterministic law was. By all practical tests progress along this new branch track must be recognized as a great advance in knowledge. No doubt some will say "Yes, but it is often necessary to make a detour in order to get round an obstacle. Presently we shall have passed the obstacle and be able to join the old road again." I should say rather that we are like explorers on whom at last it has dawned that there are other enterprises worth pursuing besides finding the Northwest Passage; and we need not take too seriously the prophecy of the old mariners who regard these enterprises as a temporary diversion to be followed by a return to the "true aim of geographical exploration." But at the moment I am not concerned with prophecy and counterprophecy; the important thing is to grasp the facts of the present situation.

SECONDARY LAW

Let us first try to see how the new aim of physical science originated. We observe certain regularities in the course of nature and formulate these as laws of nature. Laws may be stated positively or negatively, "Thou shalt" or "Thou shalt not." For the present purpose it is most convenient to formulate them negatively. Consider the following two regularities which occur in our experience:

(a) We never come across equilateral triangles whose angles are unequal.

(b) We never come across 13 trumps in our hand at bridge.

In our ordinary outlook we explain these regularities in fundamentally different ways. We say that the first occurs because the

contrary experience is impossible; the second occurs because the contrary experience is too improbable.

This distinction is entirely theoretical; there is nothing in the observations themselves to suggest which type a particular regularity belongs to. We recognize that "impossible" and "too improbable" can both give adequate explanation of any observed uniformity of experience, and the older theory rather haphazardly explained some uniformities one way and other uniformities the other way. In the new physics we make no such discrimination; the union obviously must be on the basis of (*b*) not (*a*). It can scarcely be supposed that there is a law of nature which makes the holding of 13 trumps in a properly dealt hand impossible; but it can be supposed that our failure to find equilateral triangles with unequal angles is only because such triangles are too improbable. Of course, my remark does not refer to the theorem of pure geometry; I am speaking of regularities of our experience and refer therefore to the experience which is supposed to confirm this property of an equilateral triangle as being true of actual measurement. Our measurements regularly confirm it to within the highest accuracy attainable and no doubt will always do so; but according to modern theory that is because a failure could only occur as the result of an exceedingly improbable coincidence in the behavior of the vast number of particles concerned in any experimental measurement.

We must, however, first consider the older view which distinguished type (*a*) as a special class of regularity. Accordingly there were two types of natural law. The earth keeps revolving round the sun because it is impossible it should run away. Heat flows from a hot body to a cold because it is too improbable that it should flow the other way. I call the first type primary law, and the second type secondary law. The recognition of secondary law was the thin end of the wedge that ultimately cleft the deterministic scheme.

For practical purposes primary and secondary law exert equally strict control. The improbability referred to in secondary law is so enormous that failure even in an isolated case is not to be seriously contemplated. You would be utterly astounded if heat flowed from you to the fire so that you got chilled by standing in front of it, although such an occurrence is judged by physical theory to be not impossible but improbable. Now it is axiomatic that in a deterministic scheme nothing is left to chance; a law which has the ghost of a chance of failure cannot form part of the scheme. So long as the aim of physics is to bring to light a deterministic scheme, the pursuit of secondary law is a blind alley since it leads only to probabilities. The determinist is not content with a law which prescribes that, given reasonable luck, the fire will warm me; he admits that

that is the probable effect, but adds that somewhere at the base of physics there are other laws which prescribe just what the fire will do to me, luck or no luck.

To borrow an analogy from genetics, determinism is a dominant character. We can (and indeed must) have secondary indeterministic laws within any scheme of primary deterministic law—laws which tell us what is likely to happen, but are overridden by the dominant laws which tell us what must happen. So determinism watched with equanimity the development of indeterministic law within itself. What matter? Deterministic law remains dominant. It was not foreseen that indeterministic law when fully grown might be able to stand by itself and supplant its dominant parent. There is a game called "Think of a number." After doubling, adding, and other calculations, there comes the direction "Take away the number you first thought of." We have reached that position in physics, and the time has come to take away the determinism we first thought of.

The growth of secondary law within the deterministic scheme was remarkable, and gradually sections of the subject formerly dealt with by primary law were transferred to it. There came a time when in some of the most progressive branches of physics secondary law was used exclusively. The physicist might continue to profess allegiance to primary law but he ceased to utilize it. Primary law was the gold to be kept stored in vaults; secondary law was the paper to be used for actual transactions. No one minded; it was taken for granted that the paper was backed by gold. At last came the crisis and physics went off the gold standard. This happened very recently and opinions are divided as to what the result will be. Professor Einstein, I believe, fears disastrous inflation and urges a return to sound currency—if we can discover it. But most theoretical physicists have begun to wonder why the now idle gold should have been credited with such magic properties. At any rate the thing has happened and the immediate result has been a big advance in atomic physics.

We have seen that indeterministic or secondary law accounts for regularities of experience, so that it can be used for predicting the future as satisfactorily as primary law. The predictions and regularities refer to average behavior of the vast number of particles concerned in most of our observations. When we deal with fewer particles the indeterminacy begins to be appreciable, and prediction becomes more of a gamble; till finally the behavior of a single atom or electron has a very large measure of indeterminacy. Although some courses may be more probable than others, backing an electron to do anything is in general as uncertain as backing a horse.

It is commonly objected that our uncertainty as to what the electron will do in the future is due not to indeterminism but to ignorance. It is asserted that some character exists in the electron or its surroundings which decides its future, only physicists have not yet learned how to detect it. You will see later how I deal with this suggestion. But I would here point out that if the physicist is to take any part in the wider discussion on determinism as affecting the significance of our lives and the responsibility of our decisions, he must do so on the basis of what he has discovered, not on the basis of what it is conjectured he might discover. His first step should be to make clear that he no longer holds the position, occupied for so long, of chief advocate for determinism, and that if there is any deterministic law in the physical universe he is unaware of it. He steps aside and leaves it to others—philosophers, psychologists, theologians—to come forward and show, if they can, that they have found indications of determinism in some other way.² If no one comes forward the hypothesis of determinism presumably drops; and the question whether physics is actually antagonistic to it scarcely arises. It is no use looking for an opposer until there is a proposer in the field.

INFERENTIAL KNOWLEDGE

It is now necessary to examine rather closely the nature of our knowledge of the physical universe.

All our knowledge of physical objects is by inference. Our minds have no means of getting into direct contact with them; but the objects emit and scatter light waves, and they are the source of pressures transmitted through adjacent material. They are like broadcasting stations that send out signals which we can receive. At one stage of the transmission the signals pass along nerves within our bodies. Ultimately visual, tactual, and other sensations are provoked in the mind. It is from these remote effects that we have to argue back to the properties of the physical object at the far end of the chain of transmission. The image which arises in the mind is not the physical object, though it is a source of information about the physical object: to confuse the mental object with the physical object is to confuse the clue with the criminal. Life would be impossible if there were no kind of correspondence between the external world and the picture of it in our minds; and natural selection (reinforced where necessary by the selective activity of the

² With a view to learning what might be said from the philosophical side against the abandonment of determinism, I took part in a symposium of the Aristotelian Society and Mind Association in July, 1931. Indeterminists were strongly represented, but unfortunately there were no determinists in the symposium, and apparently none in the audience which discussed it. I can scarcely suppose that determinist philosophers are extinct, but it may be left to their colleagues to deal with them.

lunacy commissioners) has seen to it that the correspondence is sufficient for practical needs. But we cannot rely on the correspondence, and in physics we do not accept any detail of the picture unless it is confirmed by more exact methods of inference.

The external world of physics is thus a universe populated with inferences. The inferences differ in degree and not in kind. Familiar objects which I handle are just as much inferential as a remote star which I infer from a faint image on a photographic plate or an "undiscovered" planet inferred from irregularities in the motion of Uranus. It is sometimes asserted that electrons are essentially more hypothetical than stars. There is no ground for such a distinction. By an instrument called a Geiger counter electrons may be counted one by one as an observer counts one by one the stars in the sky. In each case the actual counting depends on a remote indication of the physical object. Erroneous properties may be attributed to the electron by fallacious or insufficiently grounded inference, so that we may have a totally wrong impression of what it is we are counting; but the same is equally true of the stars. The rules of inference are the laws of physics; thus the law that light travels in straight lines enables us to infer the location of distant objects; and so on. In fact a law of physics can be used either way—to predict an effect from a cause or to infer a cause (i. e., a physical object embodying certain properties) from an observed effect.

In the universe of inferences, past, present, and future appear simultaneously and it requires scientific analysis to sort them out. By a certain rule of inference, viz, the law of gravitation, we infer the present or past existence of a dark companion to a star; by an application of the same rule of inference we infer the existence on August 11, 1999, of a configuration of the sun, earth, and moon, which corresponds to a total eclipse of the sun. The shadow of the moon on Cornwall in 1999 is already in the universe of inference. It will not change its status when the year 1999 arrives and the eclipse is observed; we shall merely substitute one method of inferring the shadow for another. The shadow will always be an inference. I am speaking of the object or condition in the external world which is called a shadow; our perception of darkness is not the physical shadow, but is one of the possible clues from which its existence can be inferred.

Of particular importance to the problem of determinism are our inferences about the past. Strictly speaking our direct inferences from sight, sound, touch, all relate to a time slightly antecedent; but often the lag is more considerable. Suppose that we wish to discover the constitution of a certain salt. We put it in a test tube, apply certain reagents, and ultimately reach the conclusion that it

was silver nitrate. It is no longer silver nitrate after our treatment of it. This is an example of retrospective inference: The property which we infer is not that of "being *X*" but of "having been *X*."

We noted at the outset that in considering determinism the alleged causes must be challenged to produce their birth certificates so that we may know whether they really were preexisting. Retrospective inference is particularly dangerous in this connection because it involves antedating a certificate. The experiment above mentioned certifies the chemical constitution of a substance, but the date we write on the certificate is earlier than the date of the experiment. The antedating is often quite legitimate; but that makes the practice all the more dangerous, it lulls us into a feeling of security.

RETROSPECTIVE CHARACTERS

To show how retrospective inference might be abused, suppose that there were no way of learning the chemical constitution of a substance without destroying it. By hypothesis a chemist would never know until after his experiment what substance he had been handling, so that the result of every experiment he performed would be entirely unforeseen. Must he then admit that the laws of chemistry are chaotic? A man of resource would override such a trifling obstacle. If he were discreet enough never to say beforehand what his experiment was going to demonstrate, he might give edifying lectures on the uniformity of nature. He puts a lighted match in a cylinder of gas and the gas burns. "There you see that hydrogen is inflammable." Or the match goes out. "That proves that nitrogen does not support combustion." Or it burns more brightly. "Evidently oxygen feeds combustion." "How do you know it was oxygen?" "By retrospective inference from the fact that the match burned more brightly." And so the experimenter passes from cylinder to cylinder; the match sometimes behaves one way and sometimes another, thereby beautifully demonstrating the uniformity of nature and the determinism of chemical law. It would be unkind to ask how the match must behave in order to indicate indeterminism.

If by retrospective inference we infer characters at an earlier date and then say that those characters invariably produce at a future date the manifestation from which we inferred them, we are working in a circle. The connection is not causation but definition, and we are not prophets but tautologists. We must not mix up the genuine achievements of scientific prediction with this kind of charlatanry, nor the observed uniformities of nature with those so easily invented by our imaginary lecturer. It is easily seen that to avoid vicious

circles we must abolish *purely* retrospective characteristics—those which are never found as existing but always as having existed. If they do not manifest themselves until the moment that they cease to exist, they can never be used for prediction except by those who prophesy after the event.

Chemical constitution is not a retrospective character though it is often inferred retrospectively. The fact that silver nitrate can be bought and sold shows that there is a property of *being* silver nitrate as well as of *having been* silver nitrate. Apart from special methods of determining the constitution or properties of a substance without destroying it, there is one general method widely applicable. We divide the specimen into two parts, analyze one part (destroying it if necessary) and show that its constitution *has been* X ; then it is usually a fair inference that the constitution of the other part *is* X . It is sometimes argued that in this way a character inferable retrospectively must always be also inferable contemporaneously; if that were true it would remove all danger of using retrospective inference to invent fictitious characters as causes of the events observed. Actually the danger arises just at the point where the method of sampling breaks down, viz, when we are concerned with characteristics supposed to distinguish one individual atom from another atom of the same substance; for the individual atom can not be divided into two samples, one to analyze and one to preserve. Let us take an example.

It is known that potassium consists of two kinds of atoms, one kind being radioactive and the other inert. Let us call the two kinds K_α and K_β . If we observe that a particular atom bursts in the radioactive manner we shall infer that it was a K atom. Can we say that the explosion was predetermined by the fact that it was a K_α and not a K_β atom? On the information stated there is no justification at all; K_α is merely an antedated label which we attach to the atom when we see that it has burst. We can always do that however undetermined the event may be which occasions the label. Actually, however, there is more information which shows that the burst is not undetermined. Potassium is found to consist of two isotopes of atomic weights 39 and 41; and it is believed that 41 is the radioactive kind, 39 being inert. It is possible to separate the two isotopes and to pick out atoms known to be K_{41} . Thus K_{41} is a contemporaneous character and can legitimately predetermine the subsequent radioactive outburst; it replaces K_α which was a retrospective character.

So much for the fact of outburst; now consider the time of outburst. Nothing is known as to the time when a particular K_{41} atom will burst except that it will probably be within the next thousand

million years. If, however, we observe that it bursts at a time t we can ascribe to the atom the retrospective character K_t , meaning that it had (all along) the property that it was going to burst at time t . Now according to modern physics the character K_t is not manifested in any way—is not even represented in our mathematical description of the atom—until the time t when the burst occurs and the character K_t having finished its job disappears. In these circumstances K_t is not a predetermining cause. Our retrospective labels and characters add nothing to the plain observational fact that the burst occurred without warning at the moment t ; they are merely devices for ringing a change on the tenses.

The time of break up of a radioactive atom is an example of extreme indeterminism; but it must be understood that according to current theory all future events are indeterminate in greater or lesser degree, and differ only in the margin of uncertainty. When the uncertainty is below our limits of measurement the event is looked upon as practically determinate; determinacy in this sense is relative to the refinement of our measurements. A being accustomed to time on the cosmic scale, who was not particular to a few hundred million years or so, might regard the time of break up of the radioactive atom as practically determinate. There is one unified system of secondary law throughout physics and a continuous gradation from phenomena predictable with overwhelming probability to phenomena which are altogether indeterminate.

The statement that all phenomena have some degree of indeterminacy will probably be criticized as too sweeping. I will consider just one example. I have said that a K_{39} atom is not radioactive. Then (it will be said) we can at least state one predetermined fact about its future; we can predict without any indeterminacy that it will not break up as a K_{41} atom would do. The answer of modern physics is that strictly speaking there is no such thing as a K_{39} atom, but only an atom which has a high probability of being K_{39} . Such an atom should contain 39 protons within a small nucleus; but the proton in modern physics has a very important peculiarity, viz, it never is anywhere quite definitely though it may have a greater probability of being in one place rather than another. Thus we can never get beyond a high probability of 39 protons being collected together. It is impossible to trap modern physics into predicting anything with complete determinacy, because it deals with probabilities from the outset.

It has seemed necessary for clearness to give an example of an event believed to be widely indeterminate; but you must not suppose that I have brought forward the phenomenon of radioactivity as evidence for indeterminism. There is a widespread idea that

physicists, having spent a few years investigating certain phenomena and being baffled to discover a cause, have jumped to the conclusion that there is no cause. That is not the way in which the idea of indeterminacy came into physics. I have tried to explain how it originated in the earlier part of this address.

CRITICISM OF INDETERMINISM

In saying that there is no contemporaneous characteristic of the radioactive atom determining the date at which it is going to break up, we mean that in the picture of the atom as drawn in present-day physics no such characteristic appears; the atom which will break up in 1960 and the atom which will break up in the year 150000 are drawn precisely alike. But, you will say, surely that only means that the characteristic is one which physics has not yet discovered; in due time it will be found and inserted in the picture either of the atom or of its environment. If such indeterminacy were exceptional that would be the natural conclusion and we should have no objection to accepting such an explanation as a likely way out of a difficulty. But the radioactive atom was not brought forward as a difficulty; it was brought forward as a favorable illustration of that which applies in greater or lesser degree to all kinds of phenomena. There is a difference between explaining away an exception and explaining away a rule.

The persistent critic continues, "You are evading the point. I contend that there are characteristics unknown to you which completely predetermine not only the time of break up of the radioactive atom but all physical phenomena. How do you know there are not? You are not omniscient." It is at this point I want to shout and wake my critic. So I will tell you a story.

About the year 2000, the famous archeologist Professor Lambda discovered an ancient Greek inscription which recorded that a foreign prince, whose name was given as *Καρδεικλης*, came with his followers into Greece and established his tribe there. The professor, anxious to identify the prince, after exhausting other sources of information, began to look through the letters C and K in the *Encyclopedia Athenica*. His attention was attracted by an article on Canticles who it appeared was the son of Solomon. Clearly that was the required identification; no one could doubt that *Καρδεικλης* was the Jewish prince Canticles. His theory attained great notoriety. At that time the great powers of Greece and Palestine were concluding an entente and the Greek Prime Minister in an eloquent peroration made touching reference to the newly discovered historical ties of kinship between the two nations. Some time later Professor Lambda happened to refer to the article again and discovered an

unfortunate mistake; he had misread "Son of Solomon" for "Song of Solomon." The correction was published widely, and it might have been supposed that the Canticles theory would die a natural death. But no; Greeks and Palestinians continued to believe in their kinship, and the Greek Minister continued to make perorations. Professor Lambda one day ventured to remonstrate with him. The minister turned on him severely, "How do you know that Solomon had not a son called Canticles? You are not omniscient." The professor, having reflected on the rather extensive character of Solomon's matrimonial adventures, wisely made no reply.

The curious thing is that the determinist who takes this line is under the illusion that he is adopting a more modest attitude in regard to our scientific knowledge than the indeterminist. The indeterminist is accused of claiming omniscience. I will not make quite the same countercharge against the determinist; but surely it is only the man who thinks himself nearly omniscient who would have the audacity to start enumerating all the things which (it occurs to him) might exist without his knowing it. I am so far from omniscient that my list would contain innumerable entries. If it is any satisfaction to the critic, my list does include deterministic characters—along with Martian irrigation works, ectoplasm, etc.—as things which might exist unknown to me.

It must be realized that determinism is a positive assertion about the behavior of the universe. It is not sufficient for the determinist to claim that there is no fatal objection to his assertion; he must produce some reason for making it. I do not say he must prove it, for in science we are ready to believe things on evidence falling short of strict proof. If no reason for asserting it can be given, it collapses as an idle speculation. It is astonishing that even scientific writers on determinism advocate it without thinking it necessary to say anything in its favor, merely pointing out that the new physical theories do not actually disprove determinism. If that really represents the status of determinism no reputable scientific journal would waste space over it. Conjectures put forward on slender evidence are the curse of science; a conjecture for which there is no evidence at all is an outrage. So far as the physical universe is concerned determinism appears to explain nothing; for in the modern books which go farthest into the theory of the phenomena no use is made of it.

Indeterminism is not a positive assertion. I am an indeterminist in the same way that I am an anti-moon-is-made-of-green-cheese-ist. That does not mean that I especially identify myself with the doctrine that the moon is not made of green cheese. Whether or not this lunar theory can be reconciled with modern astronomy is scarcely

worth inquiring; the main point is that green-cheeseism like determinism is a conjecture that we have no reason for entertaining. Undisprovable hypotheses of that kind can be invented ad lib.

PRINCIPLE OF UNCERTAINTY

The mathematical treatment of an indeterminate universe does not differ much in form from the older treatment designed for a determinate universe. The equations of wave mechanics used in the new theory are not different in principal from those of hydrodynamics. The fact is that since an algebraic symbol can be used to represent either a known or an unknown quantity, we can symbolize a definitely predetermined future or an unknown future in the same way. The difference is that whereas in the older formulae every symbol was theoretically determinable by observation, in the present theory there occur symbols whose values are not assignable by observation.

Hence, if we use the equations to predict say the future velocity of an electron the result will be an expression containing besides known symbols a number of undeterminable symbols. The latter make the prediction indeterminate. I am not here trying to prove or explain the indeterminacy of the future; I am only stating how we adapt our mathematical technique to deal with an indeterminate future. The indeterminate symbols can often (or perhaps always) be expressed as unknown phase angles. When a large number of phase angles are involved we may assume in averaging that they are uniformly distributed from 0° to 360° , and so obtain predictions which could only fail if there has been an unlikely coincidence of phase angles. That is the secret of all our successful prophecies; the unknowns are eliminated not by determinate equations but by averaging.

There is a very remarkable relation between the determined and the undetermined symbols which is known as Heisenberg's principle of uncertainty. The symbols are paired together, every determined symbol having an undetermined symbol as partner. I think that this regularity makes it clear that the occurrence of undetermined symbols in the mathematical theory is not a blemish; it gives a special kind of symmetry to the whole picture. The theoretical limitation on our power of predicting the future is seen to be systematic, and it can not be confused with other casual limitations due to our lack of skill.

Let us consider an isolated system. It is part of a universe of inference, and all that can be embodied in it must be capable of being inferred from the influence which it broadcasts over its surroundings. Whenever we state the properties of a body in terms

of physical quantities we are imparting knowledge as to the response of various external indicators to its presence and nothing more. A knowledge of the response of all kinds of objects would determine completely its relation to its environment, leaving only its un-get-at-able inner nature which is outside the scope of physics. Thus if the system is really isolated so that it has no interaction with its surroundings, it has no properties belonging to physics but only an inner nature which is beyond physics. So we must modify the conditions a little. Let it for a moment have some interaction with the world exterior to it; the interaction starts a train of influences which may reach an observer; he can from this one signal draw an inference about the system, i. e., fix the value of one of the symbols describing the system or fix one equation for determining their values. To determine more symbols there must be further interactions, one for each new value fixed. It might seem that in time we could fix all the symbols in this way so that there would be no undetermined symbols in the description of the system. But it must be remembered that the interaction which disturbs the external world by a signal also reacts on the system. There is thus a double consequence; the interaction starts a signal through the external world informing us that the value of a certain symbol p in the system is p_1 , and at the same time it alters to an indeterminable extent the value of another symbol q in the system. If we had learned from former signals that the value of q was q_1 , our knowledge will cease to apply, and we must start again to find the new value of q . Presently there may be another interaction which tells us that q is now q_2 ; but the same interaction knocks out the value p_1 and we no longer know p . It is of the utmost importance for prediction that a paired symbol and not the inferred symbol is upset by the interaction. If the signal taught us that at the moment of interaction p was p_1 but that p had been upset by the interaction and the value no longer held good, we should never have anything but retrospective knowledge—like the chemistry lecturer whom I described. Actually we can have contemporaneous knowledge of the values of half the symbols, but never more than half. We are like the comedian picking up parcels; each time he picks up one he drops another.

There are various possible transformations of the symbols and the condition can be expressed in another way. Instead of two paired symbols, the one wholly known and the other wholly unknown, we can take two symbols each of which is known with some uncertainty; then the rule is that the product of the two uncertainties is fixed. Any interaction which reduces the uncertainty of determination of one increases the uncertainty of the other. For example, the posi-

tion and velocity of an electron are paired in this way. We can fix the position with a probable error of 0.001 millimeters and the velocity with a probable error of about 1 km per sec.; or we can fix the position to 0.0001 millimeters and the velocity to 10 km per sec.; and so on. We divide the uncertainty how we like but we can not get rid of it. If current theory is right, this is not a question of lack of skill or a perverse delight of Nature in tantalizing us, for the uncertainty is actually embodied in the theoretical picture of the electron; if we describe something as having exact position and velocity we can not be describing an electron, just as (according to Russell) if we describe a person who knows what he is talking about and whether what he is saying is true we can not be describing a pure mathematician.

If we divide the uncertainty in position and velocity at time t_1 in the most favorable way we find that the predicted position of the electron one second later at time t_2 is uncertain to about 5 centimeters. That represents the extent to which the future position is not predetermined by anything existing one second earlier. If the position at time t_2 always remained uncertain to this extent there would be no failure of determination.³ But when the second has elapsed we can measure the position of the electron to 0.001 millimeters or even more closely, as already stated. This accurate position is not predetermined; we have to wait until the time arrives and then measure it. It may be recalled that the new knowledge is acquired at a price. Along with our rough knowledge of position (to 5 cms) we had a fair knowledge of the velocity; but when we acquire more accurate knowledge of the position the velocity goes back into extreme uncertainty.

We might spend a long while admiring the detailed working of this cunning arrangement by which we are prevented from finding out more than we ought to know. But I do not think you should look on these as Nature's devices to prevent us from seeing too far into the future. They are the devices of the mathematician who has to protect himself from making impossible predictions. It commonly happens that when we ask silly questions, mathematical theory does not directly refuse to answer but gives a noncommittal answer like 0/0 out of which we can not wring any meaning. Similarly when we ask where the electron will be to-morrow, the mathematical theory does not give the straightforward answer "It is impossible to say because it is not yet decided"—because that is beyond the resources of an algebraic vocabulary. It gives us an ordinary formula of x 's and y 's, but makes sure that we can not possibly find out what the formula means—until to-morrow.

³ For the thing we failed to predict (exact position at time t_2) would be meaningless.

MIND AND INDETERMINISM

I have, perhaps fortunately, left myself no time to discuss the effect of indeterminacy in the physical universe on our general outlook. I will content myself with stating in summary form the points which seem to arise.

(1) If the whole physical universe is deterministic, mental decisions (or at least effective mental decisions) must also be predetermined. For if it is predetermined in the physical world, to which your body belongs, that there will be a pipe between your lips on January 1, the result of your mental struggle on December 31 as to whether you will give up smoking in the New Year is evidently predetermined. The new physics thus opens the door to indeterminacy of mental phenomena, whereas the old deterministic physics bolted and barred it completely.

(2) The door is opened slightly, but apparently the opening is not wide enough. For according to analogy with inorganic physical systems we should expect the indeterminacy of human movements to be quantitatively insignificant. In some way we must transfer to human movements the wide indeterminacy characteristic of atoms instead of the almost negligible indeterminacy manifested by inorganic systems of comparable scale. I think this difficulty is not insuperable, but it must not be underrated.

(3) Although we may be uncertain as to the intermediate steps we can scarcely doubt what is the final answer. If the atom has indeterminacy, surely the human mind will have an equal indeterminacy; for we can scarcely accept a theory which makes out the mind to be more mechanistic than the atom.

(4) Is the human will really more free if its decisions are swayed by new factors born from moment to moment than if they are the outcome solely of heredity, training and other predetermining causes?

On such questions as these we have nothing new to say. Argument will no doubt continue "about it and about." But it seems to me that there is a far more important aspect of indeterminacy. It makes it possible that the mind is not utterly deceived as to the mode in which its decisions are reached. On the deterministic theory of the physical world my hand in writing this address is guided in a predetermined course according to the equations of mathematical physics; my mind is unessential—a busybody who invents an irrelevant story about a scientific argument as an explanation of what my hand is doing—an explanation which can only be described as a downright lie. If it is true that the mind is so utterly deceived in the story it weaves round our human actions, I do not see where

we are to obtain our confidence in the story it tells of the physical universe.

Physics is becoming difficult to understand. First relativity theory, then quantum theory, then wave mechanics have transformed the universe, making it seem ever more fantastic to our minds. Perhaps the end is not yet. But there is another side to this transformation. Naïve realism, materialism, the mechanistic hypothesis were simple; but I think that it was only by closing our eyes to the essential nature of experience, relating as it does to the reactions of a conscious being, that they could be made to seem credible. These revolutions of scientific thought are clearing up the deeper contradictions between life and theoretical knowledge, and the latest phase with its release from determinism marks a great step onward. I will even venture to say that in the present theory of the physical universe we have at last reached something which a reasonable man might almost believe.

THE MEASUREMENT OF NOISE¹

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The problem of noise is one common to all civilized nations and its steady increase with the industrial development of the present generation is becoming a matter for concern. The mechanization and growth of road transport, for example, have brought in their train a sea of noises in which a large number of people are daily submerged.

One reads that visitors to London extol it as the quietest capital city in the world. If so, the merit is wholly relative. It is understood, in this connection, that inquiries into the question of noise are being conducted in certain cities abroad, for example, Paris, Rome, and Berlin. New York, probably the outstanding example of a mechanized city, and admittedly the noisiest, has already set about the problem with characteristic expedition and remarkable thoroughness. A recent comprehensive report called *City Noise*, published in 1930 by the Noise Abatement Commission of the Department of Health, New York City, is a mine of information (from which I have not hesitated to draw) and a model of what a report should be which is intended to interest and educate the public and to secure its friendly cooperation. The commission, composed of eminent medical men, physicists, engineers, and lawyers, arranged for the measurement and analysis of the various types of noise in many parts of New York, succeeded in establishing a number of relations and generalizations, the truth of which had only been vaguely suspected, and so were enabled to make proposals designed to secure noise abatement wherever it might be found practicable. Certain recommendations to this end have in fact already been given effect.

In Great Britain the introduction of legislation dealing with excessive noise has so far not proved possible; and it may be that the better plan is first to educate public opinion. Traffic noises have, however, been the subject of conferences under the auspices of the Ministry of Transport, while aircraft noises are being studied by a

¹ Paper delivered at the weekly evening meeting of the Royal Institution of Great Britain, May 8, 1931; reprinted by permission.

subcommittee appointed in 1929 by the Aeronautical Research Committee. To both these bodies I am indebted for permission to refer to certain of the problems investigated.

Noise occasioned by the frequent repetition of street cries, cab whistles, etc., is frequently the subject of local by-laws, which impose penalties for infringement. The Middlesex County Council is seeking powers next session to deal with excessive, unreasonable, or unnecessary noise, on much the same lines as other nuisances are dealt with under the public health act. Several towns, for example, Edinburgh and Stockton-on-Tees, have recently taken steps to obtain similar powers.

City noises are, of course, no new thing, and no doubt London, ever since it became a big city, has always been noisy in its business thoroughfares. Steel tires and horseshoes on cobbles or stone or granite sets were very noisy combinations in Victorian times, as may still be verified in certain industrial towns. Asphalt or wooden-surfaced roads and, above all, pneumatic tires must have brought great relief.

But to-day is a machine age with noise as one of its by-products, and the volume of traffic through busy streets is now such as to create a background of noise, the level of which is brought home by a stroll through the city on Sundays, or even more on the occasion of the two minutes' silence on Armistice Day.

Among the sufferers from the growth of traffic noise are schools in busy thoroughfares, which find that classrooms fronting on the street are well-nigh unusable, unless windows are kept closed to the detriment of ventilation. By reason of the volume of industrial and other traffic which now flows through the High in Oxford, many rooms in adjacent colleges have become almost impossible for lecturing, study, or examinations. Conversation and telephoning are matters of difficulty in many city offices. Some London hospitals are in extremely busy streets, and the steady "grumble" of the traffic roar, combined with the more trying irregular outbursts of constituent noises, must be prejudicial to the welfare of some, at any rate, of the patients. Nature has unfortunately not equipped the ears with a device for excluding sound during sleep, in the same way as she has provided eyelids for resting the eyes.

According to the New York commission, many motor horns are unnecessarily loud—some of them, it is stated, can be heard 10 miles away in the quiet of the country. However, those who like to reflect on the good old days may care to recall that the giant horn by which Alexander the Great called his armies together is reputed to have had much the same range.

So far in Great Britain, the menace of the public loudspeaker has not attained the dimensions which it has reached in America. Giant sound amplifiers now make it possible to hear the human voice nearly 2 miles away, and we learn that last Christmas, carols were broadcast by this means for 10 hours over an area of some 9 square miles. The center of this acoustical disturbance was the eighty-first floor of the Empire State Building—the latest and highest (1,250 feet) skyscraper in New York.

As regards the effect of noise on human beings, there would appear to be a volume of medical testimony in this country that the strain of heavy traffic and other types of continuous din may act as a powerful irritant to the nervous system; placid and normally unruffled persons tending to become irritable and “worn out.” Industries such as shipbuilding, boilermaking, cotton weaving, and printing are, it is stated, prone to give the workers cumulative fatigue, dizziness, headaches, and impaired hearing. Even relatively minor noises, such as that of an electric fan or vacuum cleaner, can be extraordinarily irritating at times. It is only when the noise is stopped that the pronounced sense of relief makes one realize that one has been unconsciously bracing one’s self against the noise all the time. Some such reaction no doubt occurs to noise during sleep, and may perhaps contribute to the difficulty which some people have of obtaining really refreshing sleep in a railway sleeping-car.

In October, 1928, the British Medical Association submitted to the Ministry of Health a valuable memorandum dealing with the effect of noise on human beings. Their conclusions were in close accordance with those arrived at by the New York Noise Commission, who found that:

(1) Hearing is apt to be impaired in those exposed to constant loud noises.

(2) Noise interferes seriously with the efficiency of the worker; it lessens attention and makes concentration upon any task difficult.

(3) In the attempt to overcome the effect of noise, great strain is put upon the nervous system, leading to neurasthenic states.

(4) Noise interferes seriously with sleep, even though in some cases it appears that the system is able to adjust itself so that wakefulness does not result.

(5) It is well established that the normal development of infants and young children is hindered by constant loud noises.

These conclusions are in general harmony with those of the International Labor Office of the League of Nations, which in a recent paper stressed the importance of the subject of the fatigue produced by noise in relation to occupations.

Reaction to noise is no doubt largely temperamental, and acuteness of hearing varies widely in different people. There are those to whom noise is absolute anathema. It is stated, for example, that Carlyle had a sound-proof room to work in, and again that Edison was inclined to attribute to the quietness with which his deafness had invested him, much of his success in finding solutions to his problems. According to Professor Spooner, Herbert Spencer used to plug his ears with cotton-wool and even went the length of declaring that "you might gauge a man's intellectual capacity by the degree of his intolerance of unnecessary noises."

Such sensitivity to noise may be bound up with the fact that even a limited exposure to very loud noises—such as on an airplane flight—has the effect of making some people partly deaf for some minutes or even hours after the noise ceases.

It appears to be the case, however, that many people get used to noisy surroundings and adjust themselves unconsciously to the conditions. The man whose house abuts on the railway becomes indifferent to the noise of a passing train, no longer notices it, has acquired a "habit" of noise in fact. There are those who, accustomed to sleep with a clock in their bedrooms, wake up if it stops ticking. One hears, too, of people used to sleeping in the hubbub of a town who can not court slumber in the quietness of the country. O. Henry, for example, sang the praises of the pandemonium of the city streets. In his *Adventures of Neurasthenia* he protested that he could not sleep without the comforting lullaby of noise, and that the silence of the country was so deep that he could "hear the grass blades sharpening themselves against each other."

It is even claimed that a love of noise has become common and chronic in America, much as in the Latin countries; and the fact that children love noise, at any rate of their own making,² is advanced in favor of the view that a feeling for noise is bred in the bone, born out of the fact that noise must have been an indispensable friend of primitive man in his hunting and fighting. Indeed, it is suggested that one's "jump" or response to a sudden strident or discordant noise is a survival of the old instinctive reaction to a menacing danger. Be that as it may, it is no doubt a fact that a great many people are partial to mixed "musical noises," particularly in their lighter moments. The haters of jazz, on the other hand, seek to associate such a liking with immaturity, arrested education, or even worse!

² This applies also to children of a larger growth. A man hammering, for example, finds the noise much less trying than do his neighbors. It would seem that the ear automatically desensitizes itself temporarily when it is aware of the impending arrival of a loud sound.

The question of noise tolerance seems, however, to be largely one not only of sensitivity, whether chronic or temporary, but of the "background" of noise that one is used to. If external sounds are completely excluded, adventitious noises are the more trying. An amusing illustration is provided in Mary Kingsley's book on West Africa (1897), where she complains that "The African is usually great at dreams and has them very noisily!"

It is within the experience of us all that the ticking of a clock, the scratching of a mouse, the creaking of floors or furniture, the chirping of birds are aggravatingly apparent during the stillness of night in the country: such noises would be submerged in the higher noise level of a city dwelling. What is unconsciously desired is not so much the complete exclusion of noise, but only that the background shall be at an agreeably low level to which one is accustomed.

To sum up, the searching investigations undertaken on behalf of the New York commission would indicate that, while most individuals, particularly the hale and hearty, can accustom themselves to living or working in a noisy environment, there can be little doubt that, in general, noise has a harmful effect on the mind, even of those who are to all appearances immune to it. The evil effects are emphasized in the case of mental workers, young children, nervous or fatigued individuals, and invalids.

Before passing on, it is interesting to recall that "noise-money" was at one time a recognized payment at sea. We read in Chambers' Journal for 1883 that:

So disagreeable is this fog-signaling duty . . . that . . . the whole crew receive what they call noise-money . . . for the time the signal is actually in operation.

DEFINITIONS OF NOISE

Before going further, we should, I think, do well to try to come to some agreement as to what we mean by a noise. To begin with, "noise" has ominous etymological relationship with "nuisance" and "noxious;" and so, by analogy with the famous definition of dirt, there is perhaps some justification for referring to noise as "sound out of place." Although we should scarcely expect to find this definition in the New Oxford Dictionary, we are nevertheless given an almost embarrassing choice reflecting the wealth of shades of meaning which the word has assumed. In the sense, however, with which we are at present concerned, we find that noise is there defined as:

A loud or harsh sound or din of any kind; the aggregate of loud sounds arising in a busy community.

The latter use of the word is well established, for, as long ago as 1651, we find in Hobbes's *Leviathan*, I, ii, 5:

Obscured and made weak; as the voyce of man is in the noyse of the day.

One is apt to forget, however, that at one time a noise is connoted "an agreeable or melodious sound." In the Bible, Moses refers to the "noise of them that sing," and David repeatedly enjoins us to "sing and make a joyful noise." It is an easy step to the next definition:

A band, or company of musicians.

Shakespeare uses the word in this sense in *King Henry IV* (2, ii, 4):

And see if thou canst find out Sneak's noise;

Mistress Tearsheet would fain hear some music.

This obsolete association of noise with a band would seem to be entering on a new lease of life, if one may judge from certain developments of modern music!

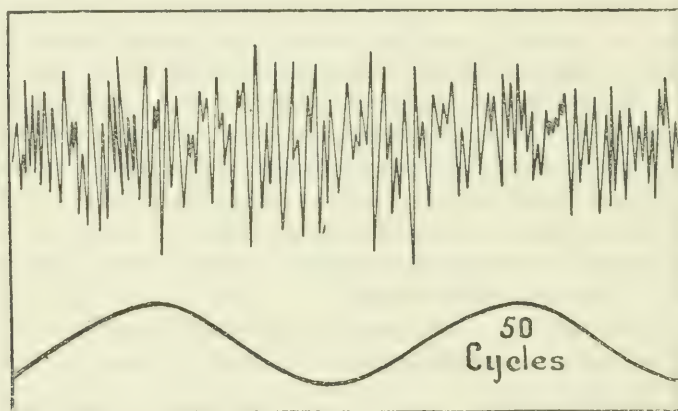


FIGURE 1.—Wave form of sound emitted by a motor generator set

Most textbooks on physics would, I think, differentiate a musical sound from a noise by investing the latter with a complexity arising from complete irregularity of period, amplitude, and wave form. In other words, a noise is to be regarded as a medley of notes of definite frequencies, the mixing being sufficiently random to obscure the musical quality of the individual notes. See, for example, Figure 1, from observations by Churcher and King. (*Journ. Inst. Electr. Engs.*, 1930.)

As is very easy to demonstrate, it is, however, possible to generate a note of high purity, but of such intensity or frequency as to be voted a thoroughly objectionable "noise" by those who hear it. We had better, I think, turn to the legal definition of noise. In law, noise may be defined as an excessive, offensive, persistent, or startling sound. Incidentally, by the common law of England, freedom from noise is essential to the full enjoyment of a dwelling house, and acts which affect that enjoyment may be actionable as nuisances. But it has been laid down that a nuisance by noise, supposing malice to

be out of the question, is emphatically a question of degree. Only if a noise is exceptional and unreasonable, is there any likelihood of restraining it by injunction. (Encycl. Brit.)

So much for the legal aspect. It does, however, appear to point to an acceptable popular definition of noise—"an acoustic redundancy"—or perhaps "an acoustic annoyance," and here we are reminded that the adjective "noisome" is literally "annoy-some." (One recalls, too, that children have long been concerned with the annoyance factor of noise as experienced by an oyster!)

In other words, a noise is an acoustic disturbance which is unwelcome, whether because of its excessive loudness; its composition; its persistency or frequency of occurrence (or alternatively, its intermittency); its unexpectedness, untimeliness, or unfamiliarity; its redundancy, inappropriateness, or unreasonableness; its suggestion of intimidation, arrogance, malice, or thoughtlessness (it is well known what depth of feeling can be stimulated in a pedestrian by a motor horn); . . . and so on.

We are clearly dealing with a subjective definition which takes account of both the physiology and psychology of the individual, and we ought not, therefore, to be surprised to find that "One man's noise is another man's music." Incidentally the well-known fact that listening to music engenders in some people an unquenchable desire to converse, is doubtless associated with the rough-and-ready test which we instinctively apply to a noise, that is, whether or not we can hear one another speak. Conversation automatically languishes in a tube train or airplane cabin, for example.

We are fortified in our outlook on noise by the recent proposal of the Acoustical Society of America to define a noise as "any unwanted sound." Such a definition would seem to be adequate for those few occasions when it is necessary or desirable to draw a distinction between noise and any other kind of sound. It also conforms to the views of the telephone engineer who regards noise as any extraneous sound which tends to interfere with the reception of desired sounds.

THE FREQUENCY AND INTENSITY RANGES OF THE EAR

As is the case in many branches of science, the physics of acoustical research owes its present facility and exactitude largely to the development of electrical methods of measurement. The key lay in the invention of the electronic valve, and to this the subject owes an impetus which it had long needed.

Before we pass on to the question of noise measurement we shall be well advised to review the relevant physical facts about the ear, which is, of course, the ultimate critic in matters of noise. The foundations of the subject rest largely on experiments with pure notes,

and here it should be recognized how greatly our present knowledge of both hearing and speech is due to the noteworthy investigations of Dr. Harvey Fletcher and his colleagues at the Bell Telephone Laboratories in New York.

With reference to frequency, the average ear can perceive a range of frequencies from about 20 to 20,000 cycles per second, the upper limit declining with advancing years. In the various practical developments of acoustics, however, attention is largely restricted to the ranges 50 to about 5,000 for speech and 35 to 7,000 for music.

As regards intensity, it has been shown by Wegel and others, from experiments on pure notes, that there is a certain minimum amplitude

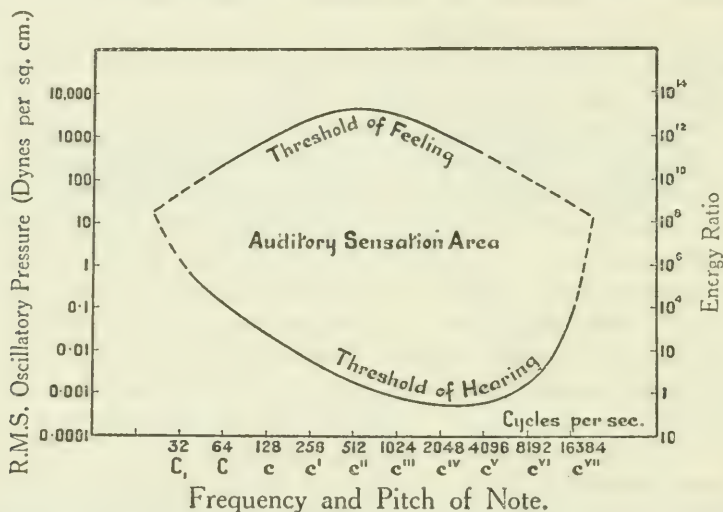


FIGURE 2.—Average area of normal hearing, showing auditory ranges of frequency and intensity

for each frequency below which the average ear fails to detect the note. Moreover, the ear is much more sensitive to notes of medium pitch than to higher or lower notes. The threshold or lower limit of intensity passes in fact through a minimum at about 2,000 cycles per second as we steadily change the frequency.

Similarly there is a maximum amplitude peculiar to each frequency, above which the ear no longer functions—hearing is subordinated to a tickling sensation or even actual pain. Again the ear shows to advantage in the middle of the range (about 500 cycles per second), and so the upper limit of intensity or threshold of feeling passes through a maximum as we progressively vary the frequency.

Figure 2 shows the auditory sensation area for the average ear as determined by Fletcher and Wegel. (Fletcher's Speech and Hearing.) The boundaries are constituted by the two threshold curves,

the dotted portions being those which are difficult to determine. We see that the range of audibility passes through a maximum (at about 1,000 cycles per second) as the frequency is varied, and is greatly reduced toward each end of the musical scale. This maximum range corresponds to about a million millionfold variation in power, or a millionfold variation of acoustical pressure from about, say, 0.0005 to 3,000 dynes per square centimeter. We note also in the case of very high and very low notes the great intensity that is essential for audibility and how restricted the range of audibility is. A familiar illustration is the sound from a 32-foot organ pipe which one feels rather than hears.

As will presently appear, the matching and masking of sounds form the basis respectively of two aural methods of measuring the loudness of noise; and it will be of interest, therefore, to examine the basic physical facts of each method.

THE MATCHING OF SOUNDS

As regards the matching of sounds, it is found that the average ear can recognize under very favorable conditions a 10 per cent³ difference of energy when two pure notes of medium loudness are sounded alternately without break. Under ordinary conditions, however, the smallest average change in energy level detectable by the normal ear is of the order of 26 per cent for sounds of medium intensity and frequency. The figure is greater for feeble sounds and less for very loud sounds. The value is also greater for very high or low frequencies than for the middle of the range.

From the fact that it is a percentage increase rather than an additive increase of energy which the ear associates with a change of loudness, it is evident that, while the steps in the scale of sensation of loudness advance arithmetically, the physical intensities advance geometrically, the relation thus resembling the logarithmic scale of powers of a slide rule. Here is, then, another illustration of the Weber-Fechner law—the physiological effect is roughly proportional to the logarithm of the energy producing the stimulus.

Kingsbury (Fletcher's Speech and Hearing, p. 230) has carried out experiments on the matching of pure tones to determine the relation between the physical intensity and the aural loudness for different frequencies. These experiments indicated that for frequencies between about 700 and 4,000 cycles per second, the relation between loudness and intensity is independent of the frequency. For notes of lower frequency the loudness increases proportionately more

³ This figure is more than doubled if there is an interval of silence between the two notes of as little as half a second.

rapidly than the intensity. Kingsbury's results are set out in Figure 3, which shows a number of equal loudness contours superposed on the auditory sensation area. As will be seen, these contours are roughly parallel to each other for medium frequencies above about 700 cycles per second.

An experimental illustration based on such loudness contours is to operate a pure sound at constant intensity and gradually increase the frequency, when the loudness will be heard to pass through a maximum at about 2,000 cycles per second. This is evidenced by the track of the horizontal line in Figure 3 at a level of about 0.1 dyne per square centimeter.

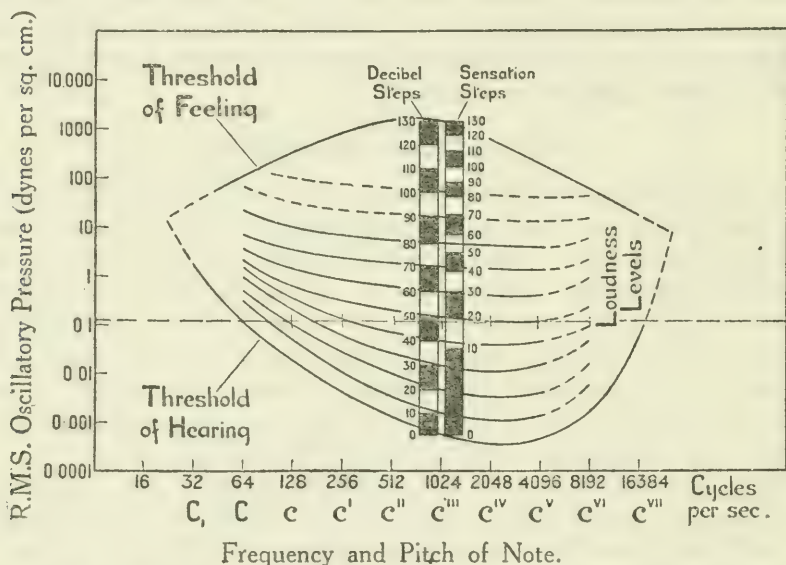


FIGURE 3.—Auditory sensation area showing equal loudness contours; also decibel "ladder" and sensation-step "ladder" for a frequency of 1,000 cycles per second

THE MASKING OF SOUNDS

With reference to the masking of sounds, the masking of one pure note by another is usually measured by the extent to which the threshold of audibility of the masked note is raised. In general a particular note is masked (1) most readily of all by another of approximately the same frequency, (2) more readily by a note of lower frequency than one of higher, at any rate for loudnesses about and above speech level.

The position is not so simple with loud complex sounds, such as noises, as the masking may be confused by other factors, such as the masking of the individual components and the formation of subjective tones. (Fletcher's Speech and Hearing.)

THE DECIBEL

We are now aware of the area of auditory sensations which we have to mensurate, and we have to decide what is to be our "yardstick" or "degree." Our task is to try to correlate aural loudness with physical intensity or energy; and already we have seen that while the sensation of loudness advances, as it were, by simple addition, the energy level increases by leaps and bounds on a scale which extends over almost astronomical magnitudes. This is a cumbersome relation, and it is clear that there will be a real convenience in adopting a scale of ratios of energy for our purpose. A similar need which arose in telephone engineering was met by the introduction of the "bel," a name chosen in honor of Alexander Graham Bell, the inventor of the telephone. One "bel" expresses a tenfold increase of power or energy; in other words, two intensities in the ratio $r:1$ differ by $(\log r)$ bels.⁴ It has been generally agreed to adopt the bel for acoustic requirements also, or rather the "decibel" (db.), since the "bel" is a little too large for the purpose. We thus have the following tabular relation:

Ratio (r) of intensities	Number of decibels ($10 \log r$)
1	0
10	10
100	20
1,000	30
10,000	40
—	—
10^{13}	130

It will be realized that this scale of decibels is in no sense physiological but is based wholly on intensity as measured by physical methods. The scale has, however, the specific advantages—

- (1) Of being a rough fit with the aural scale of loudness sensation.
- (2) That experiment shows that the decibel, as above defined, corresponds approximately to the least perceptible change in loudness of a sound of medium loudness under average conditions. In actual fact the loudness step in question is sometimes a little more and sometimes a little less than a decibel (ranging from 0.2 to 9 db.) according to the frequency and the location in the auditory sensation area.

We are now in a position to set up a definition of the sensation level of a pure note of specified frequency in physical terms. Our "degree" will be the decibel, our "zero" the threshold of audibility for that frequency, and the sensation level of a pure sound

⁴ Logarithms are to base 10.

may accordingly be defined as the intensity in decibels above the threshold of audibility of that frequency.

On this basis experiment shows that for pure sounds of medium frequency the range of audibility between the thresholds of hearing and feeling is covered by about 130 decibels. This figure is rather less for high and low frequencies.

The position, however, is not so straightforward when we come to the broader question of comparing the loudness of pure sounds of different frequencies. We find at once that there is no simple relation of wide application between physical intensity and loudness. Two pure sounds of different frequencies do not in general produce the same loudness sensation, even if (a) their physical intensities are equal, or (b) their physical intensities bear the same ratio to their respective threshold values, i. e., if the sounds have equal sensation levels. Further, if the intensity levels of two pure sounds of different frequencies which appear equally loud are increased by the same amount, the sounds will not in general remain equally loud.

It follows that in the case of sounds of different or mixed frequencies neither the physical intensity level nor the sensation level can be used as a measure of loudness. In the circumstances we have to adopt an arbitrary scale as a practical standard, and a suitable one for the purpose is the sensation scale of a pure note having a frequency in the region of 1,000 cycles per second. Then the loudness of any sound, whether pure or a mixture such as noise, is defined as the sensation level (expressed in decibels above the threshold value) of the standard note which appears equally loud to the ear. It may be mentioned that zero or threshold value of a 1,000-cycle scale corresponds to a pressure of about a millidyne per square centimeter.

It should be reiterated that such a standard scale is quite arbitrary and that equal increments on the scale do not in general approximate very closely to an equal number of sensation steps. For instance, in the case of the 1,000-cycle scale, the step from 0 to 10 decibels corresponds roughly to about 1 perceptible gradation of loudness under average conditions, the step from 50 to 60 contains about 10 gradations, and the step from 100 to 110 about 15. In other words, we may ascend the range of physical intensity lying between the two thresholds either by the decibel ladder, with equally spaced rungs, or by the sensation-step ladder, with rungs first widely spaced and afterwards more narrowly, though more evenly, spaced (fig. 3).

It may be added that, in adopting a practical scale of loudness, some latitude is possible in the choice of the standard frequency, in view of the fact that for medium frequencies above 700 cycles per second there is a constant relation between loudness and sensa-

tion level. For example, the standard frequency chosen for much of the work at the National Physical Laboratory is 800 cycles, while in the United States 1,000 cycles has been largely used.

SPEECH AND NOISE

As already remarked, the masking effect of a background of noise on the ease of conversation is one of primary interest. Conversation begins to be difficult when the background of noise reaches 70 or 80 decibels, while at 90 decibels conversation, even by shouting, is virtually impossible.

It should be remembered that the greater part of the energy of the human voice is in the low-frequency region. Some 60 per cent of the energy lies in frequencies below about 500 cycles per second, and about 85 per cent below 1,000 cycles per second. It is known, however, that the intelligibility of speech rests largely on the high-frequency consonants—say, above 1,000 cycles per second—rather than on the low-frequency vowels (say, 120 cycles for the male voice and 240 cycles per second for the female), despite the fact that the low-frequency components carry the major part of the energy.

Davis and Evans at the National Physical Laboratory have observed that conversation in an inclosure is facilitated if high-pitched noises are excluded from without. It is fortunate that such notes can be more readily excluded than low notes, and particularly so, where limits are set to the massiveness of the walls of the inclosure, as in an aeroplane cabin. Furthermore, such high notes as gain entrance are more readily absorbed by mounting absorbent on the inner walls. (Davis, *Journ. Roy. Aer. Soc.*, 1931.)

As regards the effects of noise on the hearing of speech, Knudsen found in 1925 that if the interfering sound is a pure note at about speech level, the interference with speech is almost independent of frequency, but that for greater intensities low-pitched notes interfere more than high. He also states that the interfering effect of noise is greater than that of a pure note whatever the pitch. Figure 4 (due to Mr. Fleming) summarizes Knudsen's results on the effect of extraneous noise on the intelligibility of speech as interpreted by articulation tests with speech of normal loudness (50 db.). As will be seen, even a little noise affects speech reception adversely, while a noise level of some 30 or 40 decibels reduces the intelligibility by an intolerable amount.

ANNOYANCE AND NOISE

We have already referred to the association of annoyance and noise, and the question has recently been the subject of experiment. Precise measurement could scarcely be expected, perhaps, but it is clear that both frequency and loudness are among the factors which

play a part. As to pitch, it is probable that the majority of people find shrill sounds more offensive than low. They find, for example, the high-pitched motor horn, to the staccato use of which the Paris taxi driver is so addicted, more irritating than the lower-pitched horn which normally obtains in Great Britain. This impression is confirmed by the work of Laird and Coye (*Journ. Acoust. Soc. Amer.*, 1929), who found that annoyance is a function of both loudness and pitch, high pitches being intrinsically more annoying than low or medium pitches, and very loud high pitches being especially irri-

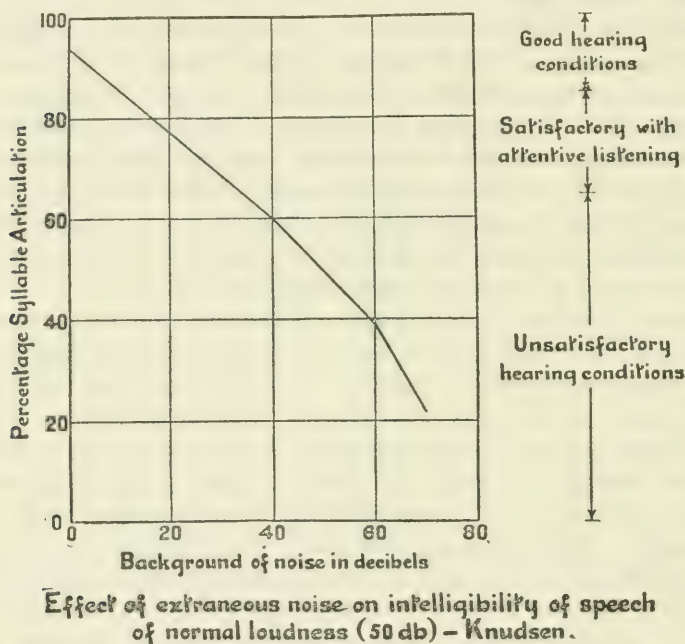


FIGURE 4

tating. In the case of pitches below about 500 cycles per second, the annoyance was, however, purely a matter of loudness. In this connection it is of considerable interest to note that the range of pitches which man normally employs in his own speech appears to be the least annoying to him. The irritation produced by certain tenor and soprano voices is claimed by Laird and Coye as being in harmony with their findings.

The annoyance produced by complex noises such as those resulting from motor horns appears to be largely influenced not only by sheer loudness but also by the presence of strong high-frequency components as well as by strong inharmonic components.

Some such explanation may also account for the fact that although, for example, two fans or two vacuum cleaners may appear

equally loud by an audiometer test, yet the noise of one may be more objectionable than that of the other.

THE ABSOLUTE MEASUREMENT OF ACOUSTICAL ENERGY

A standard method of measuring the absolute energy of waves in general is to absorb them completely in some suitable material and measure the amount of heat generated. But, even if such absorption were possible in the case of sound waves, the absolute amounts of energy in speech and most other sounds of everyday experience are so small as to be on the border line of the capacity of the most sensitive heat measuring instruments we have. For example, the average speech power of the conversational voice is about 10 microwatts. This value rises to about 1,000 microwatts for the shouting voice, falls to 0.1 microwatt for the quietest speech, and to about 0.001 microwatt for the softest whisper. To take an illustration, a final cup-tie crowd of 100,000 at Wembley Stadium all talking continuously and rather loudly would provide as much speech-power as would, if converted, light a small electric lamp throughout the game. Alternatively, by the end of the match the acoustical energy expended would have been sufficient, if transformed into heat, to boil enough water to make one cup of tea. An especially enthusiastic crowd which shouted vigorously all the time might similarly manage 10 cups—perhaps enough to fill the challenge cup itself!

There are, however, one or two outstanding examples of acoustic disturbances in which substantial amounts of energy are involved. Measurements in New York on ships' sirens have shown a power level of about 6 microwatts per square centimeter at a distance of 115 feet, so that the total acoustic energy emitted by the siren would appear to be about one-third horsepower. King (Phil. Trans. A., 1919) found an acoustic output of 1.7 horsepower in the case of a fog siren.

For sounds of ordinary magnitude, however, it is clear that the outlook for thermal methods of measuring acoustic energy absolutely is not promising, and we must turn to some other property of the sound waves. The oscillatory variation of the air pressure in the track of the advancing sound wave, the accompanying minute changes of refractive index and of temperature, the velocity of the oscillating air particles, and the radiation pressure exerted on a reflecting surface have all been employed. A conversational sound corresponds to an alternating pressure (R. M. S.) of about 1 dyne per square centimeter,⁵ in other words, to a pulsation of one millionth part of the atmospheric pressure. The change in refractive

⁵ It is estimated that the street noise of New York exerts an average pressure of about 5 dynes per square centimeter and may even reach 20.

index for such a pressure variation is about one part in a thousand million, the temperature variation about one one-thousandth degree centigrade, the particle velocity of the air about one-fortieth centimeter per second, and the radiation pressure only some 10^{-11} of an atmosphere. The corresponding power is about one one-thousandth microwatt per square centimeter, it being recalled that the power (or energy) varies as the square of the pressure and the amplitude.

For the purposes of absolute measurement we are led to look for a measuring instrument which will give readings independent of both frequency and wave form of the sound. One of the most convenient is the Rayleigh disk, which measures the air or particle velocity.

The Rayleigh disk (suggested by the late Lord Rayleigh in 1882) consists of a thin circular disk hanging vertically from its edge by a torsion thread, the disk being of small diameter compared with the wave length of the sound to be measured. Such a disk when placed in a sound field experiences a couple which tends to set the disk broadside on to the direction of the sound waves, much as a falling leaf tends to flutter to the ground flatwise instead of edgewise. As König showed in 1891, the turning couple is independent of the frequency of the sound concerned, and so we are enabled to calculate the particle velocity in the sound wave, provided we measure the deflection of the disk, and the torsional constants of the system.

If the experimental conditions are such that the sound field is of known distribution (for example, pure plane or spherical progressive waves free from boundary reflections), the oscillatory pressure at any point may be readily calculated from measurements of the particle velocity.

In practice disks of thin silvered glass about 1 centimeter diameter are often employed, the suspending fibers being of quartz some 15 centimeters long and about 5×10^{-3} diameter. The disk is mounted in an inclosure the walls of which are heavily lined with absorbent.

As would be imagined, the Rayleigh disk is a fragile instrument which is to be regarded rather as an ultimate standard of reference, the use of which is necessarily restricted to the standardizing laboratory. More convenient and robust instruments are essential for practical purposes, and recourse is usually had to electrical microphones, preferably of a nonresonant type. These translate acoustical oscillations into electrical oscillations which are amplified by a suitable valve amplifier, and so can be conveniently and accurately measured, provided proper precautions are taken.

A variety of other devices, many of them of the mechanically resonated type, have also been proposed from time to time as sound

measurers or recorders, but for a number of reasons their use has been almost entirely discontinued in favor of electrical microphones, particularly those of the condenser or electrostatic type.

The condenser microphone consists essentially of a metal diaphragm tightly stretched and mounted parallel and very close to a metal plate, the gap being only about one one-thousandth inch. The thin section of air inclosed materially adds to the stiffness of the stretched diaphragm so that its resonant frequency is very high—usually above the normal range of acoustic frequencies. To the condenser formed by the plate and diaphragm a potential difference of about 200 volts is applied through a high resistance. Sound waves incident on the diaphragm cause it to vibrate, resulting in variations of the capacity of the condenser, which, in turn, produces across the series resistance an alternating electromotive force which can be readily valve-amplified and so measured, by means of a rectifier (such as a thermojunction) and microammeter. Alternatively the wave form may be examined by a cathode-ray oscillograph. The condenser microphone, though somewhat insensitive, enjoys the advantage of a fairly uniform response over the acoustic range of frequencies, and thus provides a useful standard instrument, which can be calibrated in absolute units.

At the National Physical Laboratory and elsewhere in Great Britain such calibrations have usually been carried out by direct substitution with the Rayleigh disk in a simple sound-field. In the United States, until recently, particular attention has been paid to calibration by means of the thermophone, an instrument in which the alternate heating and cooling of a gold or platinum leaf by a fluctuating electric current produces calculable pressure oscillations within a small inclosure. It is now generally recognized that these two types of calibration lead to different results, and that the Rayleigh disk is required for the normal use of a microphone in free air, and the thermophone if measurements are to be made of the oscillatory pressure in a small inclosure, such as an artificial ear canal.

THE MEASUREMENT OF NOISE

It was, I think, Lord Kelvin who said that once we find out how to measure a thing, we begin to learn something about it. As regards noise, however, it is evident from the foregoing that the question of its measurement is one of some complexity, involving not only physics but physiology and psychology. Nevertheless, as far as the physical aspect goes, it is clearly desirable that there should be a consensus of opinion on the choice of a system of physical quantities. They should be preferably of an absolute character, so as to assist inter alia:

- (a) In translating vague aural judgments and comparisons into facts and figures;
- (b) In elucidating the causes and characteristics of noises;
- (c) In comparing the results of different investigators; and
- (d) In setting up such arbitrary standards of noise as may be desired in the light of social, technical, or legal requirements.

The practical measurement of noise usually comprises one or more of the following operations:

- (1) The physical measurement of the "over-all" power or energy content of the noise, the result being ultimately expressible in absolute units (e. g., dynes or microwatts per square centimeter).
- (2) The physical analysis of the noise into its spectrum of frequency components (cycles per second). This is often most illumi-

Physical Measurement of Noise.

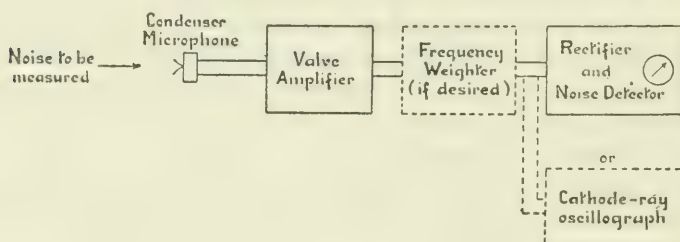


FIGURE 5

nating in tracking down the sources of individual components, particularly of machinery noises.

(3) The physical determination of the wave form of the noise, though this is often difficult to interpret and to utilize quantitatively, particularly if the noise is aperiodic.

(4) The aural measurement in some accepted unit of the loudness of the noise, or in other words, the valuation of the "noisiness" as perceived by the ear—the physiological arbiter of noise.

PHYSICAL MEASUREMENT OF NOISE

We have already discussed the measurement of sound energy by means of the condenser microphone and amplifier. A schematic layout is shown in Figure 5. The amplified current is connected either to a rectifier and microammeter (graduated in decibels, if desired) for measurement purposes, or alternatively to a cathode-ray oscillograph if it is desired to examine the wave form. In view of the fact that the microammeter readings are measures of physical intensity and not of loudness (owing to the selective sensitivity of the ear to pitch), a frequency-weighting network is sometimes inter-

polated in the circuit with the object of approximating the results more closely to the average aural interpretation. The weighting curve may conveniently be chosen for a loudness corresponding to that of a 1,000-cycle tone at 30 to 40 decibels above the threshold of audibility. (Free, Journ. Acoust. Soc. Amer., July, 1930.)

If it is desired to analyze the noise, this may be effected by incorporating electrical tuning or band-pass filtering devices into the circuit and so determining in turn the amount of energy associated with individual components or bands of frequency. It is not always possible, however, by such means to get sharp selectiveness, but, in any event, we have to recognize that as yet our knowledge is not sufficiently general to enable us to correlate exactly the overall loudness of a noise with the energy or loudness of its constituents.

It is possible to construct microphone and amplifier units which are reasonably portable, such as that developed by Davis at the National Physical Laboratory.

SEARCH-TONE METHODS OF NOISE ANALYSIS

The question of the practical analysis of noises which are reasonably periodic has been much facilitated by the introduction of search-tone methods, which in general enable sound to be more conveniently analyzed and with higher selectivity over a wide frequency range than is possible by the method of tuned circuits.

When search-tone methods are employed the noise to be analyzed is received in a microphone, the current of which is amplified and "mixed" in a valve-rectifier or modulator with that of a pure search tone of constant intensity and variable known frequency from a heterodyne oscillator. As a consequence, the modulated current contains not only the search tone but also the summation and difference tones formed from the search tone and the various individual constituents of the noise. For example, if the frequency of the search tone is S and that of a particular constituent of the sound is C , the frequencies of the summation and difference tones so formed will be $(S + C)$ and $(S - C)$, respectively.

One way of revealing the existence of either of these tones is to apply the modulated current to a highly selective mechanical resonator, such as a steel bar capable of vibrating longitudinally. Then, as the search frequency is varied continuously, the bar will begin to resonate whenever either $(S + C)$ or $(S - C)$ becomes equal to the natural frequency of the bar. As we know S , we can evaluate C , and, further, the degree of response of the bar, which is observed by suitable means, will give us a measure of the energy in the constituent in question. In practice S may range from, say, 11,000 to 16,000 cycles per second, while the natural frequency of the bar may well

be of the order of 16,000 cycles per second for the summation-tone method and 11,000 for the difference-tone method. (Moore and Curtis, *Bell System Techn. Journ.*, 1927.)

Grützmacher (*Elek. Nach. Tech.*, 1927; *Zeit. Tech. Phys.*, 1929) uses, instead of a mechanical resonator, a low-pass filter arranged to transmit frequencies less than about 30 cycles per second (fig. 6). It follows that, in the great majority of cases, both the search tone and all the summation tones are ruled out, and only those difference tones with frequencies less than 30 cycles per second will pass the filter and be recorded by an appropriate amplifier and detector. Thus, as the search frequency is continuously varied, the detector will only respond when the frequency is within 30 cycles per second of that of a constituent tone of the noise. The magnitude of the detector reading can be made to afford a measure of the intensity of

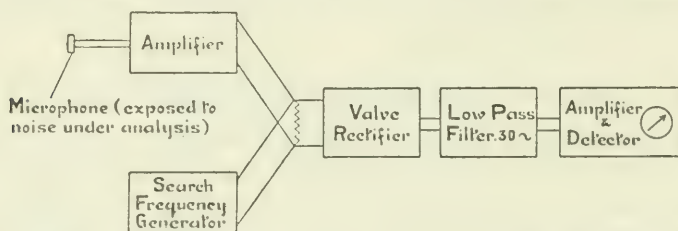


FIGURE 6.—Grützmacher's search-tone method of analyzing complex sounds

the component in question. In the outfit at the National Physical Laboratory the frequency of the search tone is varied from, say, 30 to 10,000 cycles per second by the rotation of an air condenser through 180° .

AURAL MEASUREMENT OF NOISE

As we have already seen, if we are provided with a standard pure note of medium frequency (above 700 cycles per second), the loudness of which is variable at will over a range which has been calibrated by physical means, then we can evaluate by aural matching or equality the loudness of any other pure note or, in general, of any complex note. Alternatively, measurements may be made of the loudness of the standard note which is just masked or drowned by the sound to be measured.

Figure 7 shows schematically three types of audiometers which all work on the above principle and have been much used for loudness measurements at the National Physical Laboratory and elsewhere.

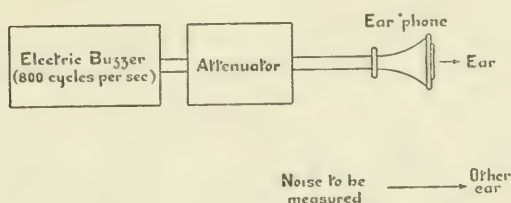
In the Siemens Barkhausen audiometer⁶ a standard note of about 800 cycles and of a high degree of purity is produced by an electric

⁶ Barkhausen, *Zeit. Tech. Phys.* vol. 7, p. 599, 1926.

diaphragm buzzer. An attenuator regulates the current through the telephone receiver, which is applied to one ear, while the other ear listens to the external noise. The instrument, which as supplied is graduated in phons,⁷ can, with a little modification, be calibrated

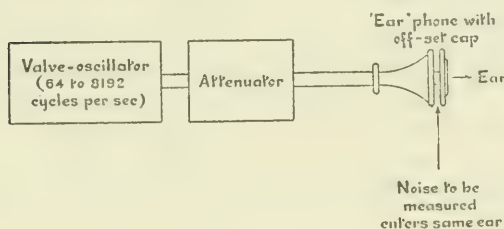
Barkhausen Audiometer.

Aural matching or masking of a buzzer note



Western Electric Audiometer.

Aural matching or masking of a valve-oscillator note.



Gramophone Audiometer.

Aural matching or masking of a warbler note.

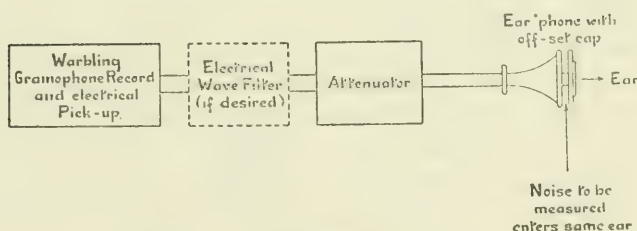


FIGURE 7

(as already described by means of a condenser microphone and an artificial ear channel) in dynes per square centimeter above a zero of a millidyne per square centimeter. The Barkhausen audiometer is compact and readily portable.

⁷ A phon corresponds to a fourfold change of energy, i. e., to a loudness change of 6 decibels.

The Western Electric audiometer offers a choice of eight standard pure notes from 64 to 8,192 cycles per second generated by a valve oscillator. (An electric buzzer is used in an earlier model first adapted in 1925 from an audiometer primarily developed for the measurement of hearing.) The instrument is graduated in steps of 5 decibels. The telephone receiver is provided with an off-set ear plate, so that the noise to be measured enters by the same ear as is applied to the telephone receiver.

In a third type of audiometer, the valve oscillator is replaced by a gramophone record and electrical pick-up. This also will furnish at will a selection of from three to six different pure notes of high, medium, and low frequency, or, if preferred, of "warbling" notes, the frequency of a complete warble being about six times a second. In practice, a 3-band warbling record may have the following frequency limits: 1,500-5,600, 750-1,500, and 250-750 cycles per second. With this audiometer, also, the same ear is normally used for both the standard note and the noise to be measured.

With all the various types of audiometer, the reading is best approached by a series of progressive comparisons alternating on either side of the critical value. When making measurements one should, as it were, try to focus on loudness, and endeavor to ignore such frequency differences as there may be. Unless one ear is abnormal, it does not seem to matter a great deal for ordinary requirements whether the standard note and the noise enter by the same ear or by different ones.

If a noise contains only two or three major components, one observer may be tempted unconsciously to match on one component, whereas another observer will seize on another component, with consequent disagreement in their results. In such cases there may be an advantage in having a choice of frequency for the standard note.

In general, however, experience indicates that most people find themselves able after a little practice to obtain fairly consistent results with even the simpler forms of audiometer, at any rate with noises which are more or less continuous. On the whole, masking results are easier to obtain than matching or equality values. In the United States, masking results are usually preferred, affording as they do a measure of the degree of "deafening" or the raising of the threshold limit for the particular frequency or band of frequencies used.

CLICKER EXPERIMENTS ON NOISE MEASUREMENT

The writer was led in 1929 to make some rough experiments on noise measurement, by the aid of a flexed steel-strip "clicker," such as is sometimes used by lecturers. The note of the clicker is high

pitched and surprisingly penetrating, and can be heard in quiet surroundings nearly 1,000 feet away. The masking range of audibility was determined under a variety of conditions. In an airplane cabin or near a pneumatic road breaker or a riveter, the range shrinks to 2 or 3 feet, while near an airplane engine the range is only a few inches. On the somewhat doubtful assumption of the inverse square law, the clicker confirmed the fact that the interior of a tube train (75 to 80 db.) is appreciably louder than that of an express train traveling at about 60 miles per hour—even in the corridor with some of the windows open (70 db.). It is, of course, common knowledge that it is difficult to converse and listen in a tube train, but not difficult in an ordinary train with the windows closed, particularly in a first-class carriage, with its more generous upholstery. The cabin of an airplane in a cross-channel flight was found to be at least one thousand times (30 db.) noisier than an express train, although the plywood cabin walls cut down the noise of the engine one hundredfold (20 db.). The preference exercised by knowledgeable passengers for seats in the rear of the cabin rather than in the region of the side propellers was confirmed, there being some 10 decibels difference. It was found that the customary practice of airplane passengers to plug their ears with cotton wool resulted in a reduction of the noise experienced by about 10 decibels.

For the longer ranges of audibility the assistance was invoked of a friend or any one else available, the interest of the general public being at times a little embarrassing.

TUNING-FORK MEASUREMENTS OF NOISE

A very convenient and portable means of measuring noise has been suggested and used by Davis at the National Physical Laboratory. (*Nature*, January 11, 1930.) A tuning fork is struck in some convenient standard manner—against the heel of the boot will do quite well, and no unusual care is necessary. The fork is then held with the flat of the prong toward the opening of the ear and as close as possible without actually touching. The time of striking the fork is noted, and the interval of time is observed until the loudness falls to the level of the surrounding noise. If desired, the time interval before the note of the fork is masked by the noise can also be measured. The rate of decay of the fork is calibrated in decibels by a buzzer or other type of audiometer. As the decay of the loudness of a fork is practically logarithmic, the calibration curve of decibels against time is roughly linear. Readings are facilitated in practice if, as the fork is approaching the matching value, it is moved to and from the ear, so that its sound is alternately louder and softer than that of the noise.

A particular fork used by Davis had a frequency of 640 cycles per second. Its loudness when it was struck was about 90 decibels and the rate of decay was about $1\frac{1}{2}$ decibels per second. Noises as high as 110 decibels were measured by means of masking observations.

Davis has used the method for determining the loudness of a variety of noises over the range of hearing, and obtained results which, as will be seen from Table 1, are in good agreement with audiometer measurements by American observers.

RELATION BETWEEN THE LOUDNESS VALUE AND THE MASKING VALUE OF NOISES

As the masking effect of a noise is dependent on its composition, theoretically it is in general not possible to associate the loudness value of a noise (as determined either physically or by aural matching) and the masking value as determined aurally by one or the other of the available audiometers. As a practical fact, however, it would appear that for most of the ordinary complex and fairly continuous noises of everyday life, the loudness value exceeds the masking by a fairly constant difference, which tends to increase somewhat for louder noises, or for those of an intermittent staccato character. (Williams and McCurdy, *Journ. Amer. Inst. Electr. Eng.*, September, 1930, and Galt *Journ. Acoust. Soc. Amer.*, July, 1930.)

For normal street and interior noises the New York commission found that on the average the loudness value exceeded the medium-frequency masking value by about 15 decibels. For a very loud noise (90 decibels), such as the intense cheering of a large crowd, it would appear from the report that the two values differed by 20 decibels. Davis (*loc. cit.*), in his tuning-fork experiments, found a like difference for a loudness of 110 decibels. He also refers to an approximately linear relation between masking and matching values for moderately loud noises.

In the case of measurements of airplane-propeller noises of very high intensity made for the Aeronautical Research Noise Subcommittee by the National Physical Laboratory the two values differed by about 20 to 30 decibels, though it will be realized that measurements at such intensities are necessarily somewhat rough.

EXAMPLES OF NOISE MEASUREMENT

Some simple illustrations of the measurement of everyday noises may be of service.

The loudness of speech ranges between about 40 and 60 decibels, an ordinary conversational tone being about 50 decibels. If, however, the lips of an average speaker are within one-half inch of the ear of a person with normal hearing, the latter will receive the speech at a level of about 100 decibels. An average motor horn sounded

about 20 feet away illustrates a loudness of about 80 decibels. Twins crying together are only 3 decibels louder than one crying alone. Another way of increasing a noise by 3 decibels is for the observer to move 30 per cent nearer (that is, when in the open air). Another 20 per cent (that is, halving the distance) and the total gain will be 6 decibels.

Loudness Levels of Common Noises

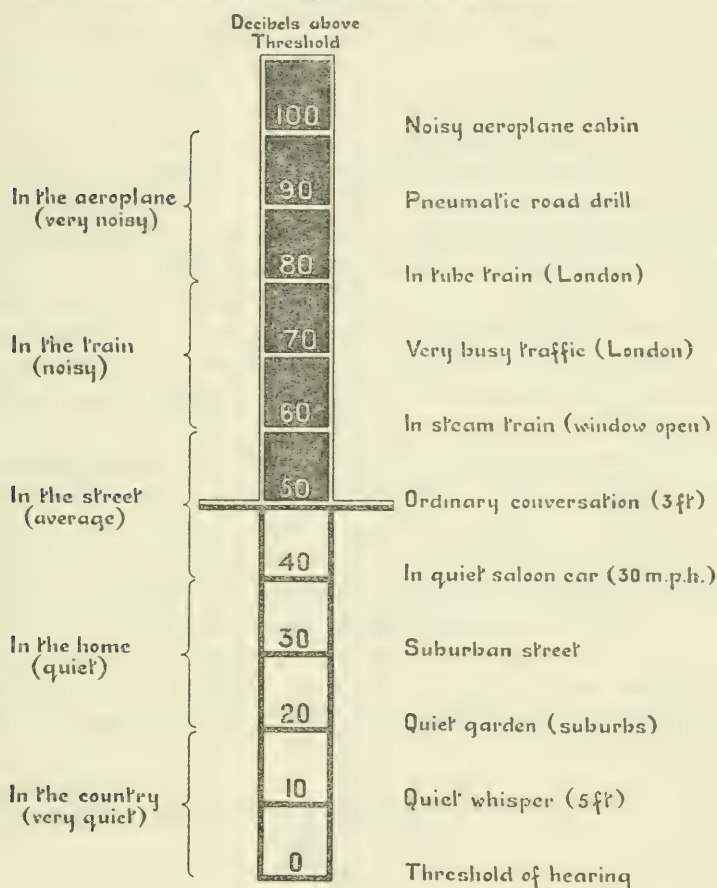


FIGURE 8

Figure 8 shows a kind of "noise thermometer" of common noises ranging up to 100 decibels—a level which is unlikely to be exceeded in everyday experience. Some broad general groupings of noises are indicated on the left. Above 50 decibels the scale is differentiated as containing in general those noises which we should do well to endeavor to moderate as far as it may be practicable to do so, and we can perhaps regard this figure as a kind of "temperate" level on our noise thermometer.

Table 1 contains a collection of loudness levels (rounded to the nearest 5 decibels) of various noises as determined in this country by the National Physical Laboratory and in the United States mainly by the New York Noise Commission (the figure for the medium frequency test note being selected). Certain points of general interest are discussed below:

Table 1 includes a variety of traffic noises both in London and New York, and, as far as it may be possible to draw a fair comparison, it would seem that a street in New York is on the average about 10 decibels noisier than a like street in London. Although there are thoroughfares in London where at times a barking dog would not be heard 20 feet away, there are traffic centers in New York where, as the commission has pointed out, a tiger could roar indefinitely without attracting the auditory attention of passers-by. It is stated that certain street corners in New York are normally noisier than anywhere so far discovered in the world; for example, the corner of Sixth Avenue and Thirty-fourth Street, which rejoices in three main streets, three tramcar lines, a double-track line of the elevated railway and the subway (underground). The arch sinner is the elevated railway, and nothing, I imagine, is less likely than that London will ever allow anything approximating to an overhead railway to override its streets.

The New York commission found that the ebb and flow of noise from hour to hour closely parallels the density of the traffic, at any rate up to a figure of 50 vehicles per minute.

Some diminution of the traffic noise heard would naturally be expected in the higher stories of a building, but the effect is largely nullified, if there are high buildings on both sides of the street. In such cases, even with skyscrapers, appreciable relief only comes to the stories just above the first setback. Wise travelers book bedrooms on the twentieth floor upward in certain hotels in New York and Chicago.

TABLE 1.—*Loudness levels of various noises*

TRAFFIC NOISES

Source	Location or distance	Average decibels above threshold	Observer
Very busy traffic, New York.....	75	Free.
Very busy traffic, London.....	70	Davis, N. P. L. ¹
Busy traffic, New York.....	70	Free.
Busy traffic, London.....	60	Davis, N. P. L.
Quiet street, New York.....	69	Free.
Quiet street, London.....	50	Davis, N. P. L.
Quiet residential street, New York.....	40	Free.
Quiet suburban street, London.....	30	Davis, N. P. L.
Quiet suburban garden, London.....	20	Do.

¹ National Physical Laboratory.

TABLE 1.—*Loudness levels of various noises—Continued*

ROAD TRANSPORT NOISES

Source	Location or distance	Average decibels above threshold	Observer
British:			
Tram on very noisy rails	In street	90	Davis, N. P. L.
Tram, or open-bus top	do.	70	Do.
Bus, recent type	Interior	50-60	Kaye, N. P. L.
Motor car, quiet	In street	50	Davis, N. P. L.
Salon car, average 25 miles per hour	Interior	40	Do.
Salon car, average, 35 miles per hour	do.	60	Do.
Salon car, quiet, 35 miles per hour	do.	40	Kaye, N. P. L.
American:			
New York street car (tram)	10-15 feet	70-75	Galt.
Do.	Interior	70	Parkinson.
Motor lorry, average	15-50 feet	70	Galt.
Motor car, average	do.	65	Do.
Motor car, quiet	do.	50	Do.
Horse vehicle, paved street	do.	75	Do.
Horse vehicle, asphalt street	do.	60	Do.
Horse, trotting	do.	60	Do.
Motor horn (British)	20 feet	80	Davis, N. P. L.
Motor horn (New York)	23 feet	70-100	Galt.
Directed at microphone		2 90	
Motor horn (New York), in street	25-100 feet	70	Do.
Police whistle (New York)	15 feet	80	Do.
Police whistle	15-75 feet	75	Do.

MISCELLANEOUS NOISES

General:			
Conversation		40-60	Galt.
Whispering	5 feet	10-40	Davis, N. P. L.
Applause (New York), Lindbergh	In crowd	90	Fletcher.
Restaurants (London)	Interior	40-70	Davis, N. P. L.
Typists' room		70	
Church bells	1,200 feet	60	Galt.
Thunder	1-3 miles	65	Do.
Animals:			
Lion roaring (New York Zoo)	18 feet	85	Do.
Siberian tiger roaring	7 feet	80	Do.
Bengal tiger snarling	15 feet	75	Do.
Dog barking in street	20 feet	65	Do.

VERY LOUD NOISES

General:			
Riveting	35 feet	95	Galt.
Do.	200 feet	80	Do.
Pneumatic drill	20 feet	90	Davis, N. P. L.
Printing-press room		90	
Steamship siren	115 feet	95	Galt.
Do.	1,500 feet	60	Do.
Steam pile-driver	20-80 feet	85	Do.
Hammering, building	100 feet	75	Do.
Niagara Falls	Noisiest spot	85	Royce.
Airplanes:			
Airplane engine	10 feet	110	Davis, N. P. L.
Do.	18 feet	115	Parkinson.
Airplane cabins, various	Interior	80-110	Davis, N. P. L.
			Evans, N. P. L.
Airplane cabin	do.	95	Parkinson.
3 airplanes in flight	3,000 feet	60	Galt.

TRAIN NOISES

British:			
Express train	12 feet	100 ?	Davis, N. P. L.
Express train, 60 miles per hour	In corridor, windows open	70	Kaye, N. P. L.
Train, windows open	Interior	60	Do.
Train, windows shut, third class	do.	55	Davis, N. P. L.
Train, windows shut, first class	do.	50	Do.
Train, windows shut, first-class sleeper	do.	45-50	Kaye, N. P. L.
Suburban electric train starting		70	Davis, N. P. L.
Tube train (London)	Interior	80	Do.
Tube train	do.	75-80	Kaye, N. P. L.

¹ Average.

TABLE 1.—*Loudness levels of various noises*—Continued

TRAIN NOISES—Continued

Source	Location or distance	Average decibels above threshold	Observer
America:			
Express (limited) train.....	Interior Pullman car.....	60	Parkinson.
Suburban train.....	Interior.....	65	Do.
New York subway, express.....	15-25 feet.....	95	Galt.
Do.....	Interior.....	95	Parkinson.
New York subway local.....	6-30 feet.....	90	Galt.
New York elevated train.....	15-20 feet.....	90	Do.
Do.....	Interior.....	75	Parkinson.

In American Pullman railway car (Parkinson):

3 decibels increase in noise for 10 miles per hour increase in speed.

5 decibels increase in noise by opening window.

5 decibels increase in noise when passing another train.

10 decibels increase in noise in tunnel.

5 decibels increase in noise in corridor.

5-10 decibels decrease in noise when berths are made up.

REFERENCES:

Davis, *Journal Royal Aeronautical Society*, 1931.

Free, *Journal Acoustical Society of America*, 1930.

Galt, *Journal Acoustical Society of America*, 1930.

Parkinson, *Journal Acoustical Society of America*, 1930.

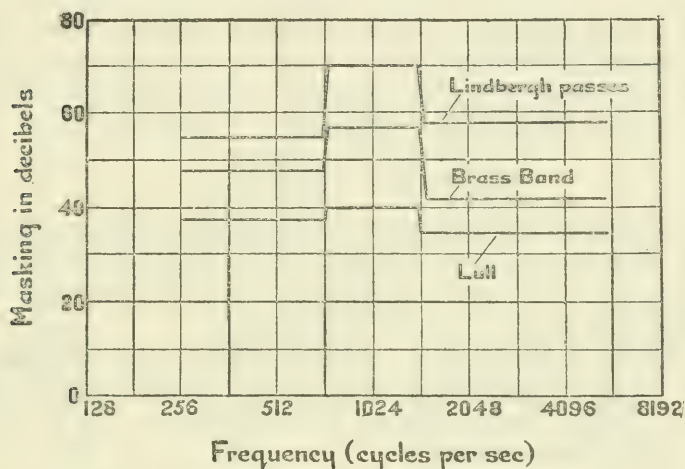
Figure 9 (due to Galt, *Journ. Acoust. Soc. Amer.*, 1929) shows masking measurements of crowd noises obtained by the use of a 3-band warbler audiometer on the occasion of Lindbergh's arrival in New York after his Atlantic flight. The observers were on the fifth floor, about 110 feet from the street. The masking effects of the noise produced by the crowd's welcome as Lindbergh passed are pronounced—quite sufficient, in fact, to mask the sound of a brass band not many yards distant. It is clear that here is a quantitative method, as Mr. Galt remarks, by which footlight and other favorites of the public can periodically assess their popularity!

As regards the individual components of traffic noise, it would seem from the limited data available that British and American tramcars do not on the average differ appreciably as regards noise. The same remark probably holds for motor cars. It is of interest to note quantitative evidence that a modern car at moderate speed is quieter than a horse vehicle on a paved street.

Among the contributory factors to traffic noise are motor horns, into the noisiness and stridency of which an inquiry of a restricted character was undertaken in 1929 by the National Physical Laboratory on behalf of the Ministry of Transport. Observations were made in a closed chamber with heavily lagged walls. Both physical and aural methods of measuring noise were employed, cathode-ray oscillograph records being also made of the average wave form. It appeared from the limited observations that stridency was bound up largely with sheer loudness, but that strong high-frequency components, strong unrelated notes, and any marked starting character-

istics were among the probable contributory factors. It was not found possible to correlate stridency with wave form. The spectra and wave forms were obtained of a particular electric klaxon with alternative types of noise, an electric buzzer, an English bulb horn (reed type), and a French bulb horn (reedless). In some of these cases, the characteristics were substantially modified by adjustment of the horn.

The New York Noise Commission arrived at much the same conclusions. They regard horns with sound levels in excess of about 90 decibels when heard 23 feet away, as unnecessary and objectionable. They find that complaints of stridency are unlikely to arise when



Crowd Noises measured 110 feet away.

FIGURE 9

fundamental frequencies lie between 200 and 300 cycles, when the overtones are all harmonics of the fundamental and share the energy evenly, and when there is an absence of strong high frequencies.

As regards trains, the noise levels of express and suburban trains in England and America seem to be not unlike for a similar class of accommodation. The American method of dividing up Pullman sleeping-cars partly by means of heavy curtains seems, despite its other drawbacks, to result in a noise level comparable with that of our own more secluded first-class sleeping berths. In such circumstances, however, much depends on other factors, such as the good fitting of doors and windows, which restrict noise admission.

With reference to underground railways, the New York subway stands in a class apart for noise—as anyone who has traveled by it will testify. Our own tubes appear to be at least 10 decibels quieter, though questions of speed may come in.

Among the loudest things one is likely to encounter are the noises of riveting, pneumatic road drilling, steamship sirens, and printing presses. More untoward events are lions and Niagara Falls, which can apparently roar equally loudly (85 decibels).

But the arch offender of all is the airplane engine at close quarters (110 decibels). The noise in the cabins of airplanes in flight ranges between 80 and 110 decibels, according to the type of machine. The noise of the propeller is probably the dominant factor, though engine exhaust and general engine clatter run it close, and all three must be seen to if an improvement is to be apparent. There are, however, good prospects that the noise in airplane cabins will presently be substantially reduced (possibly to that of a railway train) by using propellers with lower tip speeds, providing more effective silencers on the exhausts, reducing engine clatter by inclosing the engines, and constructing cabins of double walls containing a suitable filler. In this connection, see Davis (*Journ. Roy. Aer. Soc.*, 1931).

PROTECTION FROM NOISE

The best way of securing protection from noise is to quiet it at its source. This is much more effective than trying to control it later. For example, machines may be enclosed or better balanced, or better shaped, and mounted on insulating materials.

As regards traffic noise, a great deal of the more objectionable noise is due to vehicles which are ill-cared for and in bad condition or badly loaded. Indiscriminate horn-blowing is not, I think, a characteristic British trait.

Where there is considerable traffic noise, much can be done to add to the comfort of a building by creating sound shadows, and by architectural ingenuity in providing "buffer" rooms, a recent example of which is afforded by the new Headquarters of the British Broadcasting Corporation.

The protective shielding by buildings is well illustrated by the sylvan quietness of inclosed quadrangles, such as the Inns of Courts, which are in close proximity to noisy streets. The bedrooms opening on an hotel courtyard are usually much quieter than a room on the outside of the building, though sometimes the domestic quarters are so situated as to nullify the advantage.

NOISE-PROOFING WALLS

There are two main practical methods for insulating an inclosure against air-borne noises:

- (a) By using single nonporous rigid walls or partitions.
- (b) By using multiple partitions as independent as possible and separated by air or some kind of loose filling.

In the case of the single rigid type of wall, the weight is the primary factor, the insulation value (in decibels) being proportional to the logarithm of the mass of the wall per square foot of area. Prisoners in the castle dungeons of old could not have been greatly troubled by air-borne sounds! Figure 10 illustrates the measurements of Davis and Littler at the National Physical Laboratory. Their results, together with those of Knudsen, the Bureau of Standards, and others on single partitions, are summarized in

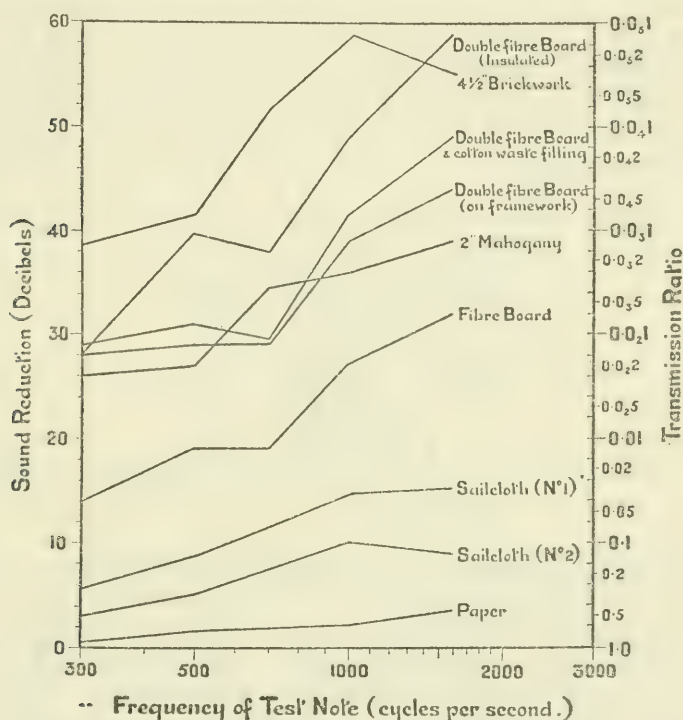


FIGURE 10.—Insulating values of various materials for notes of different frequencies. (Davis and Littler)

Table 2 for a medium frequency (512 cycles per second). The insulation values are in general rather less for low frequencies and rather more for high frequencies. As panels transmit sound mainly by diaphragm action resonance effects may come into operation at low frequencies, but under normal conditions are probably of secondary importance.

As a rough working rule, doubling the mass increases the insulation value by about 5 decibels, though resonance effects may spoil the relation.

In the case of porous flexible materials Knudsen states that the insulating value is proportional to the mass of the wall per square

foot of section rather than to its logarithm. Often a combination of the porous flexible material and the rigid dense partition is advantageous.

It may here be mentioned that for the stages of talking-film studios insulation values of from 50 to 70 decibels are aimed at according to the circumstances.

As regards multiple partitions, they should be wholly free of cross-ties, that is, completely isolated from one another, if the combination is to be any better (as it may be) than one single partition of the same over-all thickness. Whether or not a loose filling material should be sandwiched between the panels is a matter for experiment, as such a filler may or may not be beneficial. On the one hand, it may act as an absorbent and a damper of vibration, and on the other it may serve as a tie.

TABLE 2.—*Sound insulation values of rigid single partitions for air-borne sounds*

Mass per square foot of wall area	Reduction of sound in decibels	Mass per square foot of wall area	Reduction of sound in decibels
<i>Pounds</i>		<i>Pounds</i>	
0.1	9	10.0	38
.2	14	20.0	43
.5	20	40.0	48
1.0	24	60.0	51
2.0	29	100.0	54
5.0	33		

¹ 4½-inch brick wall.

The question of protection from structure-borne noises is one to which it is hoped attention may be paid in the new sound laboratories which are to be erected at the National Physical Laboratory, as there is need for systematic experiment. Heterogeneity and discontinuity appear to be of value, and loose fillers may prevent the drumming of resonant panels or walls which is often an accompaniment to such vibrations and may result in pronounced sound emission.

In many houses the windows are the chief offenders in admitting external noises. Sound-proof construction would be greatly simplified if windows could be abolished. This, of course, is not to be contemplated, but we can at any rate use substantial windows of thick glass. Opening a window even a little will, of course, largely nullify the benefit of noise shielding and absorbing devices. Within limits the amount of sound admitted by a crack or opening is proportional to its area. In the case of a door or window affording, say, 30 decibels insulation, a crack with an area one one-thousandth of that of the door would admit as much sound as passes through the door or window.

Figure 11 (due to Norris) shows the progressive increase in the noise level in a room when a window opening on to external noise was gradually opened. It will be noted that a small opening may produce a large effect.

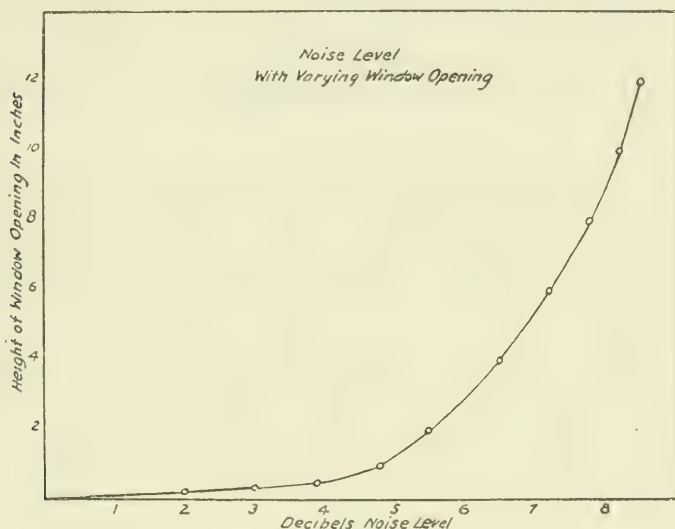


FIGURE 11

Finally, considerable advantage may accrue in preventing noise which has gained entrance into a room from building up into a high

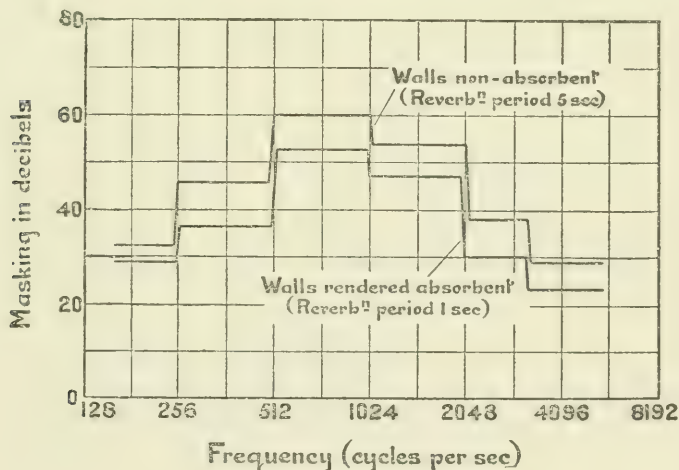


FIGURE 12.—Room noises

level of reverberant sound, by lining the walls and ceilings with absorbent materials. Certain banks and business houses in the city (London) already employ the plan with advantage. I understand

that many houses in New York line the roofs of their entrance porches with acoustic absorbent, deriving, it is stated, beneficial effects.

Figure 12 (due to Galt) illustrates the effect on masking measurements (made by a 6-band audiometer), in a room subjected to traffic noise, of lining the walls with absorbent. As will be seen, the masking value was reduced by about 7 decibels on the average, corresponding to a reduction in the reverberation period of from 5 seconds to 1 second.

THE AGE OF THE EARTH AND THE AGE OF THE OCEAN ¹

By ADOLPH KNOPF

I. THE AGE OF THE EARTH: SUMMARY OF PRINCIPAL RESULTS

At the beginning of the present century the problem of the age of the earth was envisaged as requiring the reconciliation of three independent estimates, all of the same order of magnitude. These estimates were G. H. Darwin's, of 57,000,000 years, based on the separation of the moon from the earth; Lord Kelvin's, of 20,000,000 to 40,000,000, based on the secular cooling of the globe; and Joly's, of 80,000,000 to 90,000,000, based on the rate of accumulation of sodium in the world ocean. To these should be added Helmholtz's estimate of 22,000,000 years, based on the source of the sun's heat and its probable duration.

Shortly after the opening of the century the discoveries of radioactivity destroyed the foundations on which the principal physical methods of estimating geologic time had previously rested. These discoveries, however, gave us methods based on atomic disintegration which soon indicated that geologic time is ten to twenty times as long as had been deemed probable from the estimates previously considered most trustworthy. These methods appear to involve far fewer assumptions than the geologic methods for measuring time, and the problem as we now see it is to reconcile estimates differing by a whole order of magnitude. In short, the radioactive evidence indicates that post-Cambrian time, i. e., from Ordovician onward, is 450,000,000 years, a span that is easily reconcilable with the geologic evidence, and that the age of the earth is at least 2,000,000,000 years, an estimate which, although not incompatible with the geologic evidence, is less readily reconcilable.

The oldest method for determining the length of geologic time is based on the thickness of the strata that accumulated during that time. Estimates of this kind have been made many times, but as our knowledge of the earth increases the known thickness of the strata has steadily increased. Schuchert now finds that the maximum thickness of strata on the North American continent deposited since

¹ Reprinted by permission from Bulletin of the National Research Council, No. 80, June, 1931.

the beginning of Cambrian time reaches the immense total of 259,000 feet. Of this great pile, 111,000 feet were deposited during Paleozoic time, 86,000 during Mesozoic, and 61,000 during Cenozoic. The aggregate thicknesses of strata on the other continents have never been assembled, but it is believed that eventually the pile of strata for the world will total 400,000 feet. To translate this thickness into years, even approximately, is still an unsolved problem. A mean rate of deposition that will hold for all strata can not be ascertained, and the most that can be expected is a mean for each basin of deposition. Even for limestones, which on the average take longer to accumulate than either muds or sands, the rate can not be determined.

It is therefore impossible in the light of present knowledge to check by means of the sedimentary record the time determinations that are based on radioactive disintegration. Schuchert therefore accepts the estimate of 500,000,000 years, which is based largely but not wholly on the radioactive evidence, as the best estimate we have for the span of time since the beginning of the Cambrian, and shows that the evidence of the strata can be harmonized with it. The data based on radioactivity indicate that the ratio of Cenozoic time to Mesozoic and Paleozoic is as 1:2:5; this ratio would require that one foot of sandstone be deposited in 450 years, one foot of shale in 900 years, and one foot of limestone in 2,250 years. These mean rates of deposition are faster than any heretofore used in similar estimates and are thought to be nearer the actual figures.

Some evidence is beginning to appear that the rates at which sediments were deposited in individual basins of sedimentation can be determined, and these rates will afford valuable checks on the determinations of geologic time that are based on atomic disintegration. Such measurements become possible where the strata show that they have been deposited by annual increments, each annual increment consisting of a summer and a winter lamina. The couplet, or annual layer, is called a varve. The difficulty in any given series of strata is to prove beyond question that the layers are annual—are really “varves” in fact. By counting the varves in the Green River formation, Bradley has recently estimated that this formation was deposited in a period lasting between 5,000,000 and 8,000,000 years. As the Green River formation appears to represent about one-third of Eocene time, this estimated great length of the Eocene, which is one of the shorter of the geologic time-periods, harmonizes well with the evidence from radioactivity.

By counting the varves of the Bannisdale slates, which are 5,000 feet thick, Marr² calculated that these slates were deposited in

² Marr, J. E., *A Possible Chronometric Scale for the Graptolite-bearing Strata*. *Palaeobiologica*, vol. 1, p. 161, 1928; see also *Deposition of the Sedimentary Rocks*, p. 105, 1929.

700,000 years (1 foot in 140 years). With this as a basis, he estimated that the Ordovician and Silurian together required 13,000,000 years for their deposition. Although the assumptions made in reaching this final result are admittedly large, yet we can agree with the author that "extended use of this method may lead to some approximation to the order of magnitude of the geological periods." Apparently we are on the threshold of obtaining some reliable measures of the duration of geologic time from the evidence of the strata themselves.

Schuchert has summarized the biologic evidence bearing on the question at issue and concludes that from the rate of organic evolution there can be no way of determining the length of geologic time.

Another way of measuring geologic time is based on the amount of sodium in the ocean. Given the amount of sodium washed each year into the ocean and dividing this quantity into the total amount in the ocean, there is obtained "the age of the ocean." The figure thus obtained, by Joly and by Clarke, in round numbers 100,000,000 years, has an apparent high accuracy, enhanced moreover by the fact that in reaching this figure corrections amounting to a few per cent were applied. Two large assumptions underlie the whole method; namely, that the rate at which sodium is supplied to the ocean has been constant throughout geologic time, and that the sodium has steadily accumulated in the ocean. Both assumptions are known to be untrue. The rate of erosion, or more specifically the rate of solvent denudation, has varied widely throughout time owing to varying size and height of the continents and to changing climatic conditions. The present rate of solvent denudation is probably much higher than the average rate during geologic time, but how much higher is beyond the present power of science to evaluate. Furthermore, the sodium washed into the ocean, it is beginning to appear, does not all remain dissolved but is in part removed by adsorption and base exchange with the newly deposited sediments. As we now see it, the problem of the age of the ocean based on the accumulation of sodium is not whether we can apply corrections of a few per cent to the estimate of 100,000,000 years, but whether this estimate is of the right order of magnitude.

The methods of age determination based on radioactive disintegration involve the least number of assumptions. They are explained by Kovarik and Holmes. The methods are based ultimately on the fact that the radioactive elements uranium and thorium disintegrate spontaneously at constant determinable rates and yield a stable product, lead, whose atomic weight varies according to the proportion contributed by its radioactive parents. The disintegration of uranium (and thorium) proceeds according to the laws of

a monomolecular reaction, as first pointed out by Rutherford, and if the disintegration constant is accurately known, the age of a uranium-bearing mineral can be readily and accurately determined, according to the fundamental equation,

$$\text{Age} = \frac{T_v}{\log 2} (\log U_0 - \log U)$$

where

T_v = half-life period of uranium.

U_0 = amount of uranium originally present.

U = amount of uranium now present.

In practice, however, a number of difficulties are met. Practically all uranium-bearing minerals contain more or less thorium; therefore the fundamental equation must be modified to take this into account. All equations heretofore used in age computations have been approximations. Furthermore, it can not be assumed, as has been tacitly done in the past, that no common lead was originally deposited in the uranium mineral at the time it was formed. Kovarik has developed an accurate formula, which takes account of the possibility that common lead may have been initially present in the mineral that is being used as a geologic chronometer.

In building up a geologic time scale in years based on atomic disintegration, the following conditions should obtain:

(1) The mineral must be unaltered, i. e., not changed by leaching by surface waters, or by other external processes since it was originally formed.

(2) The contents of U, Th, and Pb must be determined. Preferably these elements should be present in considerable amounts, so that the analytical errors will be minimized.

(3) The atomic weight of the lead should be determined, on lead obtained from the material analyzed for U, Th, and Pb.

(4) The geologic age of the mineral should be known.

Very few determinations—seven at most—fulfill these requisites. In fact, it has only recently been recognized that these requisites must be rigorously fulfilled, and many currently accepted age determinations rest on shaky foundations. It is probable that in the future two more conditions will have to be met: (1) The material should be radiographed, in order to determine its homogeneity, and (2) the ratio of actinium to uranium should be determined.

The determinations of ages in years that meet the critical requirements are given in the subjoined table. The age determination based on the thorite of Brevik, Norway, should on rigorous application of our criteria be excluded, because of the very small amount of lead analytically found, and the possibility that some of the lead was removed by leaching. The computa-

tions are based upon the value of the half-life period of uranium ($T_U = 4.56 \times 10^9$ years) that appears on critical scrutiny to be the most trustworthy yet determined. There is some uncertainty as to which of two is the better value for the half-life period of thorium, and so both were used in preparing the following table and the results are given in parallel columns.

Geologic age determinations based on the lead method (in years)

Geologic age	Mineral	Locality	Age (millions of years)	
			Based on $T_U = 4.56 \times 10^9$ $T_{Th} = 1.28 \times 10^{10}$	Based on $T_U = 4.56 \times 10^9$ $T_{Th} = 1.65 \times 10^{10}$
Early Permian-----	Thorite-----	Brevik, Norway-----	224	310
Latest Cambrian-----	Kolm-----	Sweden-----	450	-----
Pre-Cambrian-----	Bröggerite-----	Karlsruhe, Raade, Norway-----	915	910
Do-----	Cleveite-----	Aust-Agder, Arendal, Norway-----	967	964
Do-----	-----do-----	Satersdalen, Norway-----	986	965
Do-----	Uraninite-----	Keystone, S. Dak-----	1,465	1,462
Do-----	-----do-----	Sinyaya Pala, Carelia, Russia-----	1,852	1,852

Except for the mineral high in thorium (the thorite from Brevik, Norway), it is essentially immaterial which of the two values for the disintegration constant of thorium is taken. Only one of the substances whose age has been accurately determined by atomic disintegration, the kolm of Sweden, is precisely dated by the geologic evidence; distinctive fossils occur in the kolm and prove it to be of latest Cambrian age. The age determination of the kolm is therefore by far the most important yet made. As to the pre-Cambrian minerals, they can be only vaguely located as to their positions in the pre-Cambrian. The bröggerite from Karlsruhe, Raade, near Moss, Norway, is believed on a tenuous correlation to be middle or late pre-Cambrian, and the uraninite from Keystone, S. Dak., on which some of the finest of chemical work has been done, is thought by Paige to be late pre-Cambrian, and by Wright and Hosted to be early pre-Cambrian, but the geologic evidence adduced for either of these positions within the pre-Cambrian is inconclusive.

The uraninite from Sinyaya Pala, Carelia, Russia, appears to be the most ancient yet found, 1,852,000,000 years. As this uraninite, as well as that from Keystone, S. Dak., occurs in pegmatite dikes that are intrusive into older rocks, it must be concluded that the age of the earth is, in round numbers, at least 2,000,000,000 years. As to how much older it is, there is no substantial evidence either from geology, radioactivity, or astronomy. By a method first used by H. N. Russell, Holmes, with the aid of better geochemical data, reduces Russell's estimate of 11,000,000,000 years to 3,000,000,000

years as a possible upper limit, but this result is more interesting than conclusive.

Kovarík treats also in brief the possibility of age determination based on the helium that is formed by radioactive decay and discusses the features known as pleochroic halos, or radiohalos, as Hirschi argues they should more appropriately be called. Both these matters, however, are considered in ampler detail by Holmes in Part IV.³

In Part IV³ Holmes deals exhaustively with the application of radioactivity to the measurement of geologic time. Practically all the available information—geologic, mineralogic, and chemical—has been assembled and critically evaluated. It will be seen that this information has already attained an astonishing bulk. It is clear that the field bristles with problems. Much of the work already done is only of suggestive value, owing to the lack of correlation between the geologic, analytical, and atomic-weight investigations.

Probably the phenomena of radioactivity that come oftenest to the attention of the geologist are the pleochroic halos. They are here discussed in detail and the problems that they evoke are fully discussed. Although the halos are known to be effects of alpha particles ejected from radioactive inclosures in certain minerals, their actual mode of growth is not fully understood. Joly believes that they are of centripetal growth, but Schilling, working on the superbly developed halos in the fluorite of Wölsendorf, has demonstrated beyond much doubt that they are of centrifugal growth. Some halos have been formed by the cumulative effect of alpha particles ejected at the rate of but one a year. In pleochroic halos we have a means of detecting radioactivity ten million times more sensitive than electrical methods. Halos can not be used to determine the age of minerals, although Rutherford and Joly tried to do this for the biotite in a Devonian granite. But they had to guess the value of one factor in their calculations and, as has well been said, one might therefore as well guess the final answer. The fact of great import to the theory of age determination based on radioactivity that emerges from the study of the halos is that the rate of disintegration of "uranium" and "thorium" was the same in pre-Cambrian time as it is now. This reassuring conclusion on the constancy of the rate of disintegration of uranium during geologic time is particularly the result of the work of Kerr-Lawson, who developed an improved technique in his investigation of the halos in biotite from a pre-Cambrian pegmatite in Ontario.

The results of Holmes's world-wide survey of the data on age determination by atomic disintegration are summarized in Table LXXXII.³ The lead ratios are listed in numerical order, and the

³ Of the bulletin referred to in footnote 1 on the first page of this article.

table gives the present status of the geologic time scale as expressed in lead ratios.

Despite the fact that at present many of the lead ratios listed in Table LXXXII³ are individually weak, they are nevertheless so consistently compatible with each other from end to end that as a whole they provide a most convincing demonstration of the method.

In Part V³ Brown discusses the age of the earth from the point of view of the astronomer. The conclusion is reached that there are no known methods derived from astronomical data alone for estimating the age of the earth. The estimate based on atomic disintegration (2×10^9 years) is consistent, however, with the astronomical probabilities.

II. THE AGE OF THE OCEAN

THE PROBLEM

The age of the ocean is usually estimated by dividing the total sodium content of the ocean by the amount of sodium newly brought to it each year by the rivers of the world. The assumptions that underlie this procedure are: (1) There was no sodium in the primeval ocean; (2) the sodium washed into the ocean has been steadily accumulating, the amount lost by precipitation being negligible; and (3) the annual increment determined from present-day data has been constant throughout geologic time.

THE SODIUM OF THE PRIMEVAL OCEAN

No definitive answer can be given as to the amount of sodium in the primeval ocean. In fact, the problem is linked with our ideas on the origin of the planet. If the earth grew by the accretion of cold planetesimals according to the hypothesis of Chamberlin, the ocean must have grown slowly in size and probably in salinity. If, however, it condensed from a gaseous state, the ocean was born when the temperature fell below the critical temperature of water, 374°C. , and may have contained chlorides that were condensed or formed by the attack of hot hydrochloric acid on the crust at that time.

Joly (1899) has attempted to evaluate the amount of sodium chloride present in the "primeval" ocean, that is, the salt present in the ocean at the time it formed from the condensation of the gaseous envelope of the globe. The subtractive correction thus obtained amounted to 12.5 per cent of his estimate of the age of the ocean. F. W. Clarke, distinguished for his work on the age of the ocean by the sodium method, ignores this phase of the problem.

The great chemist, Lavoisier, considered the ocean to be the wash water of the globe. Many, however, including most German au-

³ Of the bulletin referred to in the footnote 1 on the first page of this article.

thorities, hold that the ocean has had essentially its present salinity from the beginning. Indeed this belief unconsciously tinges the whole philosophy of paleontology in regard to the origin of life as well as the development and evolution of marine invertebrate life. It will be seen that the problem of the amount of salt in the ocean at the beginning of geologic time is highly hypothetical. As, however, it will be shown that the age of the ocean as determined by sodium accumulation can not be used as a check on the far longer span of time indicated by the methods of atomic disintegration, it will be unnecessary to dilate on the question of the primeval content of sodium.

THE ANNUAL INCREMENT OF SODIUM

The total quantity of sodium in the ocean is accurately known, far more so than the other factors involved. From the data given by Clarke (1924)⁴ it is computed to be 1.609×10^{16} metric tons.

Clarke estimates that the total amount of salts carried annually to the ocean is $2,735 \times 10^6$ metric tons. This figure is obtained by multiplying the area of the globe that drains to the ocean (40,000,000 square miles) by the average amount of dissolved matter supplied by each square mile (68.4 metric tons).

	Tons per square miles	Average elevation	
		Feet	Meters ¹
North America.....	79	2,300	700
South America.....	50	1,900	580
Europe.....	100	980	300
Asia.....	84	3,120	950
Africa.....	84	2,130	650
Weighted average.....	68.4		

¹ Washington, H. S., Bull. Geol. Soc. Amer., vol. 33, p. 392, 1922.

The data for North America are good; for Europe they are less accurate; and for the other continents hardly more than guesses. Lane (1929) has recently shown that even the data for North America need revision, as the method customarily used in estimating solvent denudation gives results that are probably between 60 and 300 per cent too high. By multiplying the total run-off of a river by the chemical load obtained from one or more analyses of river water during low or medium stages, the fact is neglected that as a rule the great part of the run-off of a river is during the floods, at which time the dissolved load is at a minimum. By taking into account

⁴ Clarke uses in his computations the figure 1.413×10^{16} tons, which is based on an oceanic volume of 302,000,000 cubic miles. He accepts the estimate of 327,700,000 cubic miles by Kossinna as more accurate, but has not changed his computations; the difference, however, does not substantially affect the following arguments.

this factor, Lane shows that the age of the ocean might be as much as three times the length usually estimated by the sodium method.

The coefficient of solvent denudation obtained by Clarke, 68.4 metric tons, does not differ much from that which Reade got in his pioneer attempt, 100 tons. Of this 68.4 tons, 5.79 per cent is sodium. Therefore, the quantity of sodium carried each year to the ocean is 1.58×10^8 tons. Dividing this amount into the total oceanic sodium, we obtain as a first approximation to the age of the ocean according to the sodium method, 100,000,000 years.

The quantity of sodium annually delivered to the ocean, however, is not all a new addition to the amount already there. Part of it has been there before: this part is the so-called cyclic sodium. The most obvious form in which cyclic sodium occurs is as salt spray that has escaped into the atmosphere, has been carried inland, and has returned by the way of precipitation and drainage. Opinions differ sharply as to the corrections that should be applied for the wind-borne sodium. Joly allowed 10 per cent. Becker, by assuming that the wind-borne sodium chloride becomes nil at 20 miles inland, allowed 6 per cent, and Clarke follows him. Holland, however, has shown that in Rajputana, India, salt is carried inland 500 miles by the wind. Moreover, long extended series of determinations of the chlorine in the precipitation at Mount Vernon, Iowa, which is 1,500 miles from the Pacific coast, 1,200 miles from the Atlantic coast, and 800 miles from the Gulf, prove that salt may be carried great distances inland in quantity sufficient to account for all the chlorine shown by river-water analyses. The average of several long series of determinations by Wiesner, Knox, Artis, and Peck is 7 parts per million. The maximum amount in any one rain storm was 21 parts per million. Hendrick's recent result (1927) is somewhat lower, being 5 parts per million, but his maximum—121 parts per million—is much higher than any previous maximum. It would be interesting in future determinations to correlate the chlorine content with the origin of the storm that brought the precipitation, whether from the Pacific or the Gulf coast. Inasmuch as two-thirds of the precipitation evaporates and passes into the atmosphere practically free of chlorine, the other third, the run-off, should contain three times as much chlorine as the average amount in the precipitation. As a matter of fact, the drainage of the Central States does not carry so much chlorine, and consequently there is an unexplained discrepancy.

That portion of the sodium which is balanced by chlorine, the chloridized sodium, as it is called, may therefore be excluded as being cyclic sodium. As shown later, this exclusion is not wholly justified, as part of the chlorine in the precipitation is of volcanic

origin and is probably a new contribution to the atmosphere from the interior of the earth.

The average composition of the dissolved matter in the fresh waters of the globe, as estimated by Clarke, is shown in the subjoined table:

CO ₂ -----	35.15	Na -----	5.79
SO ₄ -----	12.14	K -----	2.12
Cl-----	5.68	(Fe,Al) ₂ O ₃ -----	2.75
NO ₃ -----	.90	SiO ₂ -----	11.67
Ca-----	20.39		
Mg-----	3.41	Total -----	100.00

The chloridized sodium in the dissolved matter is 3.68 per cent ($5.68 \times \frac{23}{35.45}$). The unchloridized is therefore 2.11 per cent; and on the assumption that this portion alone represents the sodium newly washed to the ocean each year, the annual increment of sodium to the ocean is $2.735 \times 10^9 \times .0211$, or 5.77×10^7 tons. Dividing this amount into the total oceanic sodium (1.609×10^{16} tons), we obtain 270,000,000 years as the maximum estimate of the age of the ocean. Clarke's estimate, after allowing for wind-borne sodium, human contamination, and for disseminated salt of marine origin, in all amounting to a correction of 10 per cent, is 99,143,000, or in round number 100,000,000 years.

The sodium content of the ocean, according to Clarke (1924, p. 32), has been derived from the decomposition of 84,300,000 cubic miles of average igneous rock containing 2.83 per cent of sodium. In so far as this estimate is based on the sodium content of the average igneous rock, it is approximately accurate, because the amount of sodium in the common rocks that make up the earth's crust does not vary much from Clarke's estimated average; in the two preponderant varieties of igneous rock, granite and basalt, it is 2.41 and 2.31 per cent, respectively. If we admit that the sodium in the ocean has been derived from this 84,300,000 cubic miles of igneous rock, we are faced by a great dilemma. For this volume of igneous rock contains only 0.05 per cent of chlorine and therefore can have supplied at most 2.82×10^{14} tons of chlorine to the ocean. The chlorine content of the ocean is 2.92×10^{16} tons, however. In other words, only 1 per cent of the chlorine in the ocean can have been supplied by the volume of igneous rock that is estimated to have yielded the sodium. Essentially the same argument was used by Mackie in 1903 in a penetrating analysis of Joly's method of computing the age of the ocean, an analysis to which insufficient attention has been given.

To account for this enormous discrepancy we may suppose: (1) That much more igneous rock than 84,300,000 cubic miles has been decomposed and that the sodium thus liberated and carried to the

ocean has been in part lost to the ocean, whereas the chlorine has steadily accumulated; (2) that the primitive ocean may have contained chlorine; or (3) that the chlorine has been supplied throughout geologic time by volcanic emanations, which are known to contain HCl , NH_4Cl , and other chlorides.

The supposition that a vastly greater volume of igneous rock than 84,300,000 cubic miles has been decomposed appears to be disproved by the following considerations. The volume of sedimentary rock that would have been formed from the decomposition of the 84,300,000 cubic miles of igneous rock is 108,000,000 cubic miles. If this volume of rock were spread over the continental platforms, which are 66,000,000 square miles in extent, it would make a layer 2.6 km thick. That it can be inferred from the field evidence that such a layer would probably be thicker than is the actual existing discontinuous layer of sedimentary rocks was pointed out by Van Hise, who was inclined to regard 2 km as a high estimate and 1 km as probably nearer the truth. If, in fact, 1 km is nearer right, it strengthens the growing belief that a considerable volume of sediments has been deposited in the deeper parts of the ocean and has thus become lost to the continents. At any rate, the rough agreement between the computed volume of sedimentary rocks and the inferred volume on the continents strengthens the hypothesis that the sodium in the ocean has been largely supplied by erosion of the lands.

Some sodium is lost from the ocean by the formation of glauconite, for analyses of glauconite show up to 3 per cent of Na_2O . The sodium thus lost would appear to be small, however. Sodium is also lost by the formation of albite ($\text{NaAlSi}_3\text{O}_8$) in limestones and dolomites (Spencer); but the amount thus lost, while more than commonly suspected, is probably small.

A much greater loss of sodium is due to its removal from the ocean by adsorption and base exchange. Comparison of average analyses of clays shows that marine clays contain much more soda than fresh-water clays, which difference is interpreted by Stremme as due to adsorption of sodium from the water of the ocean. That adsorption or base exchange actually occurs at the bottom of the ocean is indicated by the strong increase in the soda content of the palagonite formed by alteration of basaltic glass—the soda content has increased from 1.83 to 4.50 per cent. Chamberlin also has strongly argued for the importance of adsorption in removing sodium from the ocean.

The properties of the artificial compounds known as permutites appear to be highly significant to the problem of the removal of sodium. The sodium permutite has the composition $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2 \cdot x\text{H}_2\text{O}$; when hard water is run through a filter of sodium

permutite the calcium is removed by substitution for the sodium and the water is thus softened. When all the sodium is eventually replaced, the filter ceases to soften the water. The permutite is then regenerated by running a concentrated solution of NaCl through the filter, which is then ready to soften more water. These reactions take place according to chemical equivalents and the law of mass action. Ganssen has shown that the so-called soil zeolites present in soils are identical with the permutites. By erosion the materials of the soils are carried to the ocean. Here they come in contact with what is essentially a strong solution of NaCl and the opportunity for base exchange is afforded. Eventually they settle out and become consolidated to form the sedimentary rocks.

From these considerations it follows that much of the sodium in shales is probably of adsorptional and base-exchange origin. Therefore, since shales make up 50 per cent of the sedimentary rocks and sedimentary rocks cover three-fourths of the globe, much of the river-borne sodium has already been in the ocean; it also is cyclic sodium. From Stremme's comparison of fresh-water with marine clays it appears that one-half of the sodium in the shales may be due to adsorption and base exchange. Stremme's interesting results, however, need confirmation.

Some salt has been removed from the ocean by the deposition of the salt beds that occur in the geologic column from Cambrian time onward. Although these deposits are vast in quantity (3×10^{13} tons being estimated by Darton for the salt in the Permian beds of the American mid-continent region alone), yet they are negligible in comparison with the total amount in the ocean (4.1×10^{16} tons).

Although, then, the loss of sodium by precipitation to form salt beds has been negligible, yet the loss by adsorption and base exchange appears to have been sufficiently large to vitiate computations on the age of the ocean, especially in the precise forms given these computations by Joly and Clarke. The problem of the age of the ocean by sodium accumulation is not the validity of corrections of a few per cent to the estimate of 100,000,000 years, but of whole orders of magnitude.

Other sources of sodium chloride in river water are: (1) Human contamination; (2) salt in the sedimentary rocks, which has been entrapped in them at the time they were formed on the floor of the ocean; and (3) the gases emitted from volcanoes during eruptive activity. Of these sources only the volcanic emanations are possibly new contributions to the ocean. Chlorides are freely emitted at certain volcanoes, chiefly hydrochloric acid, though the chlorides of sodium and potassium are abundant. Vesuvius, for example, is often covered after an eruption with a white mantle of chlorides of

potassium and sodium. How much of the volcanic chlorides is a new contribution and how much, if any, is "resurgent" is not known. Recent opinion, indeed, inclines to the view that this chlorine is a new contribution from the primitive earth-stuff. Zies (1928) shows that it is highly probable that—

the discharge of acid gases from volcanoes is at least of the proper order of magnitude to supply the additional chlorine which is characteristic of the ocean as compared with the rivers.

If this is true, as it seems likely to prove, some of the chlorine found in river waters must be of volcanic origin, but how much has not been estimated.

RATE OF CHEMICAL DENUDATION

The amount of sodium that is annually supplied to the ocean is influenced by at least four factors: (1) The composition of the rocks of the surficial portion of the earth's crust; (2) climate; (3) area of the continents; and (4) height of the continents. These factors have all varied during geologic time, and therefore the rates of supply of sodium to the ocean must have varied. It is generally conceded that the present rate is abnormally high, some surmises being that it is as much as fifteen, or even twenty, times the average for all of earth's history (Barrell). But this conjectured rate applied to the aggregate rate of denudation, i. e., mechanical plus chemical denudation, and just how much the present rate of chemical denudation exceeds the average rate of chemical denudation for all of geologic time has not yet been quantitatively established.

CONCLUSION

On account of the many hypothetical and unsolved factors that enter into the determination of the age of the ocean by the sodium method, it can not be used as a check on other methods. The most that can be said is that the estimate of 100,000,000 years for the age of the ocean is probably a minimum.

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A CONTRIBUTION TO THE GEOLOGICAL HISTORY OF THE NORTH ATLANTIC REGION ¹

BY Prof. ALBERT GILLIGAN, D. Sc., F. G. S., M. I. MIN. E.

I. INTRODUCTION

There may be said to be two main branches of geological investigations—the physical and the biological—not, of course, that these can be regarded as independent or divorced from each other, but to a certain point they can make their contributions independently. For a full history, the physical and the biological changes must be known and their mutual relationship understood. It seems possible, however, that the physical history of the earth is likely to be known in much greater detail than that of the fauna and flora, for the “dry lands,” tenanted as they undoubtedly were by various forms of life, have left behind a record which can be fairly well traced on the physical side but will always refuse to yield up all its secrets on the biological side, since only rarely have the land animals and plants been preserved by a lucky chance in the rocks accumulating at the time of their existence.

The permanence of continents and ocean basins has long been a subject of controversy. Lyell, in his *Principles of Geology*, makes reference to the early ideas of the Mediterranean peoples on this subject, while Lyell himself was of opinion that continents and ocean basins do change places in the course of ages.

This idea was early challenged by both physicists and biologists. The physicists, led by Lord Kelvin, regarded the general framework of the earth as having been fixed in very early times, and Kelvin considered that the oceans and continents may have been mapped out in the original nebula from which the earth had condensed.

R. T. Chamberlin, in his book on the origin of the earth, favors a very early delineation of the present distribution of land and water, since he ascribes it to a time when the earth was still receiving planetesimal material in quantity and “growing up.” The bases of his arguments are the effects produced by atmospheric circulations, which in the embryonic earth had the same position and im-

¹ Presidential address delivered Nov. 23, 1929. Reprinted by permission from the Proceedings of the Yorkshire Geological Society, vol. 21, pt. 4, January, 1931.

portance as they now have, and effected the separation of the lighter and heavier planetesimal material, the heavier being brought down by descending currents over the oceans and the lighter being distributed over the present land surfaces. In this way he assigns a cause for the generally accepted idea of the higher specific gravity of the material of the ocean floors and the lighter material of the continental areas.

As a consequence, the suboceanic segments were habitually urged to sink, while the continents were forced to rise to restore equilibrium. This constitutes an enduring, though not an indefinitely enduring, basis for isostatic action, because the actuating differentiation is deeply inbred in the formation of the earth. Lyell had already pointed out that, with trifling exceptions, land is always antipodal to water upon the earth, and, in the language of Chamberlin, the heavy, relatively rigid, suboceanic cones stand opposite to the lighter, weaker, yielding continents. Only one twenty-seventh of the land of the globe has land antipodal to it.

The theory of the tetrahedral plan of the land and water upon the earth, as originally set forth by Lothian Green, also supports the idea of continents and oceans having existed for long periods in much the same positions as they occupy to-day. Other writers have supported the theory of the permanence of continents and ocean basins, and Russel Wallace in his *Island Life* brings forward biological evidence in support of this theory. He tabulated a number of points which went far, as he thought, to prove it, but recent researches do not support his original contentions.

In order to explain the known distribution of animals and plants in past and present times, land bridges of greater or lesser magnitude and permanency were erected by investigators, by means of which the fauna and flora could have migrated from one land mass to another.

In the case of the present North Atlantic, which is my immediate concern, an excellent paper was written by Doctor Scharff, *On the Evidences of a Former Land Bridge between Northern Europe and North America*. In this he concludes, from the known distribution of plants in North America, Greenland, Faroes, Iceland, and the British Isles, that plant migration has taken place in both directions along a land bridge connecting North America with Europe by way of the islands named. According to Scharff this bridge must have existed in later Pliocene times.

Professor Gregory, in discussing this trans-Atlantic connection, refers to the fact that remains of three mammals, the mammoth, musk ox, and reindeer, occur in northeastern America and northwestern Europe, but their passage across this land bridge is not

definitely proved, since they have not been found fossil in Iceland; and neither the mammoth nor the musk ox has been found in the Scottish highlands. In explanation he suggests that all Iceland now above sea level may have been ice-clad at the time, and that they passed over on land now submerged.

II. EVIDENCES OF RECENT SUBSIDENCE IN THE NORTH ATLANTIC REGION

The geographer royal of France, Tassin, some 250 years ago produced a map in which the sunken land of Busse or Rockall, now only a rock, is shown, and which is said to have been coasted by one of Frobisher's ships for three days.

In 1897 W. Spottiswode Green made a scientific expedition to Rockall, and he reported finding deep water on all sides, while the bank on which Rockall stands has an average depth of about 100 fathoms. Dredging on the bank yielded only such shallow water species of mollusks as could not have lived there under present conditions. All the specimens were dead, and Green argued that the bank must have subsided in comparatively recent time. In 1900 a Danish expedition reported finding littoral mollusks at considerable depths where these animals could not possibly have lived. The suggestion has been made that these animals may have been brought to their present positions by icebergs, but no icebergs reach Rockall at the present time.

Sir Archibald Geikie, in considering the distribution of the Tertiary basalts over the North Atlantic area and the manner in which they are now cut off by high vertical cliffs where they reach the coast, came to the conclusion that much foundering of the original continuous sheets must have taken place.

ATLANTIS

The theme of Atlantis has proved most attractive, and, as Professor Gregory pointed out in 1929,² it has been placed by different writers not only in some region of the Atlantic itself but also in each and every one of the bordering lands. The subject was brought prominently before the scientific world by Pierre Termier, of the Geological Survey of France, in a paper read before the Institut Oceanographique of Paris on November 30, 1912. In that paper he recalls the dialogue in the *Timæus* of Plato. The story had been handed down to Plato from Solon, who lived 600 years before the Christian era, and Solon is said to have heard it from an Egyptian priest at Sais, at the head of the Nile delta, during his visit to that country. Plato did not live to finish the work, so that all we have is

² Presidential address to the Geological Society of London. (See bibliography, p. 222.)

a fragment, as is also the case with the New Atlantis of Francis Bacon.

In the Atlantis of Plato we are told of a great island lying in the Western Ocean beyond the Pillars of Hercules. It was inhabited by the descendants of Poseidon, or Neptune, to whom Atlantis had been given when the whole earth was divided out among the gods. Plato gives a most detailed account of the form of the island, which was circular and surrounded by two other zones of land separated by zones of water.

Termier says:

We may smile in reading the story of Neptune, but the geographic description of the island is not of the sort one jokes about and forgets. The description tallies well with what we would imagine to-day of a great land emerged in the region of the Azores, a land formed from a basement of ancient rocks bearing, with some fragments of whitish calcareous terranes, extinct volcanic mountains and lava flows, black or red, long since grown cold.

The white, black, and red of Termier refer to Plato's statement that these were the colors of the rocks quarried in the island for building purposes. The story goes on to say that the land sunk beneath the waves in a single night.

Termier points out that

Near Gibraltar the depth is 4,000 meters; then it rises suddenly to Madeira and drops again to 5,000 meters between Madeira and the southern Azores. It reascends again at least 1,000 meters in the neighborhood of these latter islands, remains for a long distance between 1,000 and 4,000 meters to the south and southwest of the Azores with very abrupt projections; some of which approach very nearly to the surface of the sea. It then plunges to more than 5,000 and for a short distance to even more than 6,000 meters, rises again suddenly in a bound which corresponds with the pinnacle of the Bermudas, remains buried under 4,000 meters of water to within a short distance of the American coast, and finally rises again in a steep acclivity towards the shore.

He further alludes to the well-known fact that the eastern part of the Atlantic from Tristan da Cunha, through St. Helena, Ascension, Cape Verde Islands, the Canaries, Madeira and neighboring isles, the Azores, and the whole of the northeastern Atlantic from Antrim to Iceland, Jan Mayen, and Greenland are either active centers of volcanicity or have recently been so. The volcanic zone of the eastern Atlantic is comparable in all respects to that which borders the west of America, and like it, is geographically related to the marine depths which run parallel with them. The volcanoes of the Pacific are in genetic relationship with the down-sagging of the floor of the Pacific, and the median wrinkle, upon which lies these volcanoes in the Atlantic, may be looked upon as a mobile zone moving upward in equilibrium with the depression of the deeps on either side.

That it is the scene of active earth movement at the present time is evidenced by the great earthquake which affected Lisbon in 1755, when the center of the disturbance lay off the coast of Portugal and the waters overwhelmed the quay at Lisbon, drowning some 30,000 people.

Termier lays great stress upon the finding of tachylyte, the glassy form of basalt, at a point about 500 miles north of the Azores and at a depth of about 1,700 fathoms. In dredging for a broken cable in 1898 the grappling irons were found to be scored and scratched as if they had been drawn over the ragged edges of freshly broken rock, and on one occasion some splinters of the glassy tachylyte were found adhering to the irons. These are now preserved at the Musée de l'Ecole des Mines at Paris.

As he rightly points out, had this lava been erupted and cooled under atmospheric pressure, then the outermost part would form a thin selvage of glass or tachylyte, but if it had been erupted at the depth where it is now found, the pressure would have been such as to produce some crystalline structure. From the ruggedness of the ocean floor at this point, and the association of tachylyte with what appear to be bare rocks, he deduces a very recent submergence of the area, and also considers that this collapse was sudden.

From the inequalities in the ocean floor to the south and southwest of the Azores he argues that it is highly probable that a detailed dredging, such as was carried out to the north, would reveal a similar sunken land of recent date—

and before your eyes would increase then, almost immeasurably, the buried region, the region which was abruptly engulfed yesterday and of which the Azores are no more than the evidences escaped from the general collapse.

Geologically speaking, the Platonian history of Atlantis is highly probable.

THE FLOOR OF THE ATLANTIC

It must be clearly understood that although we have a general conception of the topography of the floor of the Atlantic, yet we have no precise knowledge of the relatively smaller elevations and depressions; and if a chart showing the soundings of the North Atlantic is examined, it will be seen how widely separated these are. It is quite possible that when a sufficient number of soundings are taken it will be found to be as irregular as the land surface, or at least it will be much more ridged and furrowed than any of the charts at present show.

The main points to be seen at present are two great depressions which run parallel with the coast lines and also parallel to another striking feature—the central ridge or rise which, starting from the

Greenland-Iceland elevation, runs through both Atlantics until it finally ends in the seventieth parallel of latitude south.

The basins are known to be subdivided by transverse small rises, so that we have the whole floor divided into basins and domes. So far, however, the folded mountain chains which end, as it seems abruptly, against the Atlantic on the Eurafrian side have not been traced with any definiteness out into the Atlantic, although representatives of these folds, of like age and similar direction, are found on the western side, as pointed out long ago by Marcel Bertrand and Eduard Suess. The mid-Atlantic Rise has been regarded by different writers as due to different causes. Haug suggested that the whole Atlantic may be regarded as an enormous geosyncline, and the Atlantic Rise he looked upon as the first evidence of the folding into mountain chains of the accumulated deposits. By others the depressions on each side are regarded as rift valleys let down on account of the movement of America and Eurafria and so widening the Atlantic Ocean. There is, of course, nothing impossible nor inconceivable in such prodigious faulting as is here implied. The boundary faults of the Central Valley of Scotland are of the same order of magnitude vertically, and in length the Atlantic faults may be compared with the Palestine-Red Sea-East Africa rifts. Such a structure would also be in agreement with that surrounding the Pacific Ocean as to magnitude, but there we have the Pacific type of coast line with its mountain chains parallel to the coast and all overturned toward the Pacific Ocean, while except for the Alleghanies in North America, the Atlantic coast line is marked by mountain chains which run transversely to it. It is to be noticed that the parallel mountain chains of eastern North America are overturned away from the Atlantic Ocean, and not toward it.

As I have already pointed out, we can not expect from the nature of the evidence to learn much of the past history of the "dry-land" areas from the biological side. On the other hand, investigations on the physical side can at once yield results of far greater value. This investigation may be applied to test the case of the North Atlantic, and the particular physical test which may be worth while undertaking is that of the character and distribution of the sediments which through the successive ages have been derived from the area now occupied by the North Atlantic and the adjacent lands.

III. THE ARCHEAN OR PRE-CAMBRIAN PERIOD

The Torridonian rocks are composed in large part of red feldspathic sandstones or arkoses and represent continental deposits, as is evident in their petrographical characters and their relation to

the underlying floor of Archean or Lewisian gneiss. This ancient land surface can be seen rising into hills 2,000 feet high, with the corresponding valleys, and the Torridonian infills the hollows and mantles round the hills, from which it is again being rapidly removed.

The description of the constituents of the coarser beds given in the Geological Survey Memoir on the Northwest Highlands points undoubtedly to the greater part of this vast accumulation of sediments having been derived from some area of land differing in rock types present from those of the older rocks of Scotland, upon which it now rests. Amongst the pebbles are found many which have been derived from sedimentary formations of an earlier age than the Torridonian sandstone, as well as pebbles of volcanic rocks such as spherulitic felsites and feldspar porphyries, some of which show striking resemblances to the Uriconian volcanic rocks of Shropshire and must have been derived from areas of volcanic rocks of which no other trace is found in the northwest of Scotland. The principal feldspars are microcline, microcline-micropertthite, orthoclase, and oligoclase, of which microcline is by far the most abundant and the least altered. The heavy minerals in their order of abundance are: garnet, zircon, magnetite, ilmenite, sphene and rutile. Monazite has also been found by Doctor Mackie.

Taken altogether the assemblage is quite unlike that which would have been yielded by a land surface of Lewisian gneiss similar to that found in Scotland. Where the Torridonian is best developed, as in Southwest Ross-shire and in Skye, it has a total thickness of nearly 3 miles, and extends for 100 miles from Cape Wrath in a south-westerly direction to the Isle of Skye, with outlying masses on the shores of Broad Bay, Isle of Lewis. Doctor Peach was of the opinion that the source of origin of the material lay to the northwest of the present Scotland.

In Scandania the metamorphosed rocks of pre-Cambrian age comprise a much more numerous suite of rocks than in Scotland, amongst which are great thicknesses of altered sedimentary rocks, but here again they are overlain by a group of red arkoses and sandstones thousands of feet in thickness which cover a wide extent of country in the heart of Norway, north of Oslo. This series of rocks is known as Sparagmite and Dala sandstone and bears a striking resemblance to the Torridonian of Scotland. The mineralogical composition of these rocks proves to be quite unlike the older granites and gneisses of the peninsula, and the assumption is that it, too, was derived from some land surface, at present unknown, which lay to the northwest. In the type region of North America there is still some doubt as to

the succession of the pre-Cambrian rocks or indeed whether great thicknesses of sedimentary rocks, classed by some workers as pre-Cambrian, may not be Cambrian or even later in age. But it is quite clear that in the so-called Algonkian or upper part of the series the thicknesses of sedimentary rocks, associated with contemporaneous lava flows, reach enormous proportions.

On the Keweenaw Peninsula of Michigan, the Upper Cambrian sandstones rest upon a great series of conglomerates, coarse red and white sandstones which are often feldspathic, and indicate accumulation under arid conditions, somewhat resembling, therefore, the Torridon sandstone of Scotland. Below the Keweenaw series come the Animikie and Huronian series. The Animikie sediments appear to have been formed in an extensive series of fresh-water or saline lakes, into which rivers carried their sediment, and the iron ores of this formation may be analogous to the bog iron ore of present-day lakes and swamps.

The Huronian contains at least 10,000 feet of clastic deposits and appears to be of continental origin and probably represents river flood-plain and alluvial fan deposits with lake-delta conditions. True boulder-clay beds are associated with this series. True red arkoses also occur at the base, and these are succeeded by red jasper conglomerates, white quartzite and chert, with limestone and slate. In the so-called Archean, below the Algonkian, are also found tens of thousands of feet of sedimentary rocks such as the Sudburian series. This series has at the base about 5,000 feet of arkose material which appears to have been derived from some distance, as the material is unlike anything in the district.

The amount of mechanical deformation which some of these originally sedimentary rocks of pre-Cambrian age have undergone in North America make it difficult to assign a source of origin to them with any certainty, but such evidence as there is points to a northerly and northeasterly source. In this connection it is to be noted that some of the formations, like the Animikian, occur in scattered areas of the Canadian Shield and stretch away far into the Arctic regions.

In Greenland and Spitsbergen nothing corresponding to the Torridonian or Sparagmite has been found, but in both occur a series of rocks consisting of quartzite, phyllites, limestone, and dolomite, known in Spitsbergen as the Heckla Hook group and certainly older than the Devonian. This series has by some authorities been assigned to a pre-Cambrian age, and it has in Spitsbergen, like the Archean on which it rests, been profoundly affected by earth movements while the Devonian above retain their horizontality, except in the west of Spitsbergen.

IV. THE CAMBRIAN, ORDOVICIAN, AND SILURIAN PERIODS

I have grouped these together because, taken on the whole, the sedimentary deposits are very similar. Locally they show great variation and ever-changing physical conditions. In western and northwestern Europe we get evidence of the proximity of shore lines with clear and possibly deeper seas extending to the east. If we consider the deposits on a line from North Wales to the Baltic Provinces of Russia and take the thicknesses of these protozoic rocks at different points along the line it will be found that they dwindle from some 30,000 feet in Wales to a few hundreds in the Baltic region, and that while they are very largely of elastic materials in the west they are organic limestones and graptolitic shales in the east.

In the Cambrian rocks of Scotland we have definite evidence of a shore line separating a land area to the northwest and a sloping sea floor to the southeast, and the oscillations of the shore line and therefore of the uplift and depression of the land and sea floor, during the accumulation of the Cambrian deposits of that area.

Similar conditions in Ordovician and Silurian times can be traced in the deposits accumulating in the neighborhood of Girvan, and the Southern Uplands doubtless was the site of coterminous deltas draining a northern land. I need only mention two of the beds which are to be regarded as derived at first hand from rocks of granitic type lying probably to the west of the present deposits; namely, the Harlech grits of the Cambrian and the massive Denbighshire grits of the Silurian.

The Lower Paleozoic deposits of North America form the mirror image of those on the European side in that to the east are the coarser sediments followed by shales farther westward, and these again still farther to the west by limestones, all these deposits being contemporaneous. There is also traceable a continual overlapping of the newer beds upon the older from west and southwest to east and northeast, e. g., at Cape Breton the Lower Cambrian is several thousand feet thick, while 30 miles to the northeast at St. John, New Brunswick, these are only 1,200 feet, and the Middle Cambrian completely overlap the Lower Cambrian still farther to the northeast. This clearly points to a depression of the land areas to the east and northeast and an encroachment of the waters which lay to the west and southwest.

V. THE OLD RED SANDSTONE PERIOD

The Old Red Sandstone, like the Torridonian, may be described as a continental deposit. The distribution of the marine Devonian and the continental Old Red Sandstone in the British Isles and Eu-

rope gives clear evidence of continental conditions existing over the northern area while marine conditions obtained to the south. The line of separation may be roughly traced from the British Channel eastward to the Ural Mountains. Oscillations of this shore line through the period are shown by the interdigitation of the continental and marine deposits in several places. Wherever the Old Red Sandstone type of deposit occurs in the British areas it consists of conglomerates, breccias, grits, sandstones, and shales, with impure limestones or cornstones in places.

The whole series is such as could only have been derived from an area in which the rocks were dominantly of granite type.

Heard and Davis have published a full account of the Old Red Sandstone of the Cardiff district, in which they show that mineralogically it bears a striking resemblance to the Torridonian and the Millstone grit of Yorkshire, and they conclude that it must have been derived from some pre-Cambrian area lying to the northwest, and its accumulation was under similar conditions to those which I have suggested for the Millstone grit of Yorkshire. The extension of the Old Red Sandstone continental area, with its characteristic flora and fauna, to Bear Island and Spitsbergen is shown by the occurrence there of thick beds of red micaceous sandstone (the Liefde Bay system) which has yielded *Cephalaspis*, *Scaphaspis*, and plant remains of Old Red Sandstone age.

In Greenland a red sandstone rests unconformably on ancient folded rocks. This sandstone has furnished no organic remains, so that its age is not definitely known, but everything points to its being the same as the Liefde Bay system (Old Red Sandstone) of Spitsbergen. This sandstone which is of great thickness occurs both on the east and west coasts, and on the west it is accompanied by porphyry.

In North America Old Red Sandstone beds are met with in the Northeastern States, in Gaspé, and New Brunswick. These represent delta deposits laid down in the northern part of the great Appalachian trough from a land mass lying off the present coast line of eastern North America. The Gaspé sandstones have a thickness of over 7,000 feet, while along the southern coast of New Brunswick similar rocks attain a thickness of 9,500 feet. In the interior these clastic deposits pass into marine sediments of Devonian type, consisting of shales and limestones.

VI. THE CARBONIFEROUS PERIOD

The clastic deposits of this period cover an enormous area in the British Isles to-day, and that area would need to be enlarged very much if we consider the conditions at the end of Carboniferous

times. If our paleographic maps are even approximately correct, the area occupied was between 80,000 and 100,000 square miles, and if they had, let us say, only an average thickness of half a mile, then on the lowest estimate we get a total volume of 40,000 cubic miles. The Mississippi to-day brings down about the twentieth of a cubic mile of sediment yearly. I have previously shown reason to believe that the bulk of the clastic material in the Carboniferous is of granite type and came from the northerly direction.

The Mississippian (Lower Carboniferous) is extensively developed (as its name implies) in the Mississippi region of Central America, southwest of the Great Lakes. When the clastic deposits were encroaching from the east, these lower beds were upraised and denuded so that the Upper Carboniferous or Pennsylvanian rests unconformably upon the several members, not only of the Mississippian, but also of the Older Paleozoic formations. The Pottsville conglomerate (the equivalent of our Millstone grit) and the succeeding Carboniferous rocks in the Appalachian region, are regarded by American geologists as having been brought into the great Appalachian Geosyncline from an easterly and southeasterly direction, overlapping one another away from the source of supply. The Lower Coal Bearing or Productive Measures overlap the Pottsville to the west and are most extensively developed in the eastern region. As in Britain, so in America; after the Pottsville conglomerate period there was a reduction in the strength of the currents, so that the lowest beds of the Productive Measures are deposited in the east only. All the higher series (Alleghany and others) were also derived from what the American geologists call "Appalachia," which was a land mass off the east coast of America. The folding of the geosyncline and uplift of the Alleghany Mountains proceeded *pari passu* with the depression of the old land from which the sediments had been derived and the coarsest eastern deposits were at the same time removed. Carboniferous rocks of the clastic type are also well developed in Nova Scotia, Newfoundland, etc.

I had the opportunity some years ago of examining many specimens of carboniferous rocks from Newfoundland, through the courtesy of Mr. Landell Mills. One interesting bed known as the Humber grit (a very appropriate name) bears a striking resemblance to such a rock as the Rough Rock, say, of Horsforth near Leeds, Yorkshire. Neither in hand specimen nor under the microscope could it be distinguished from it, and it yielded a similar suite of heavy minerals. Especially noteworthy is the feldspar, which is dominantly microcline, microcline-micropertite and oligoclase.

The physical conditions appear to have been almost identical on each side of the North Atlantic during the Carboniferous period.

Carboniferous, or at least Permo-Carboniferous, rocks occur also in Bear Island and Spitsbergen.

From the Carboniferous onward there is evidence that very little in the way of first-hand sediment was derived from what may be termed outside sources. It has been shown that the Carboniferous Rocks supplied the greater part of the breccias and sandstones of Permian age in the north of England, while in the Midlands the material was largely derived from local sources.

The conditions of the Trias were very similar, except that, as Dr. H. H. Thomas has shown, the land lying to the south of the British Isles was an important contributor.

Messrs. Greenwood and Travis, who made a detailed mineralogical examination of the Trias of the Wirral district, concluded that the Bunter had previously formed part of an earlier arenaceous deposit of granitic character, while the Keuper was derived at first hand from igneous granitoid rock situated near the site of the present Wirral Peninsula.

The Jurassic sediments have not as yet been the subject of detailed study, though there appears little evidence of far-derived material in the investigations that have so far been made.

In Northeastern America there is also no evidence that there was any great accession of freshly derived sediment from the Atlantic region after Carboniferous times.

The North Atlantic region, either by reason of its peneplanation or its subsidence, had ceased to play an active part in the supply of material for building up new lands on its periphery, though the shore lines traceable in the Scottish area through the Mesozoic period indicate that land still lay to the north and northwest. It is of some interest to note that every transgression of the British area by marine waters came from the south and the southeast, the two most notable instances, of course, being at the beginning of Mesozoic time with the Rhaetic and the still more complete Cenomanian transgression.

VII. THE CHARACTER OF THE LAND MASS: ITS SIZE AND POSITION

It has been shown that in the three great epochs, Torridonian, Old Red Sandstone, and Carboniferous, when the interpretation of the sediments has led me to infer renewed uplifts of the land mass from which the fresh sediments of these periods were derived, the mineralogical contents of these sediments are of granitic type (crushed and metamorphosed in places) with fresh and unaltered feldspars, principally microcline, microcline-microperthite, and oligoclase, and the heavy minerals confirm this conclusion. Basic rocks

appear on all counts to have been either absent or to have formed only a very small part of the area. Volcanic rocks of acid type, such as the spherulitic felsites and feldspar porphyries, denote, no doubt, surface and hypapyssal manifestations of the igneous activity bringing the granites into position. Sedimentary rocks of grits, sandstones, and chertly limestones were fairly common, and have yielded numerous pebbles to the formations named above, as well as much of the finer material.

The mica-schist pebbles represent, no doubt, altered sedimentary rocks. It is quite probable, then, that the succession on the ancient land mass may have been:

TOP. Unaltered sedimentary rocks with volcanic rocks, mica schists, quartz schists, and other altered sedimentary rocks.

BASE. A complex of acid igneous rocks, mechanically deformed, invaded by granite masses and associated dykes of pegmatites, feldspar porphyries, etc.

Can we find in the Archean lands surrounding the North Atlantic such rock types as are here indicated?

Europe.—In the portions which can now be examined in the appropriate positions in the British Isles and Scandinavia the rock types are such as could only yield a small part of the material, a real test being the microcline, and, except for some pegmatite dykes such as occur in the neighborhood of Cape Wrath, microcline is a comparatively rare mineral.

Greenland.—Here on the east and west coasts Archean rocks occur, mainly of granite with gray gneiss. The granite frequently contains hornblende, and is traversed by intrusions of syenite and sodalite syenite.

There are also quartzites, clay slates, and limestones which are correlated with the Heckla Hook system of Spitzbergen. We do not find here again those types which would yield the granitic sediments. Further, it has to be borne in mind that Silurian rocks covered much of Greenland, and these were folded and contorted by movements before the deposition of the red sandstone of Old Red Sandstone age. The Archean of this region, then, could not apparently have yielded much to the Devonian sandstone and later rocks unless, of course, the unknown interior of Greenland contains rocks of the right type, which were exposed in Old Red Sandstone and Carboniferous times.

Labrador.—Coleman says that the northeastern part of Labrador is very like the northwest of Scotland and parts of Scandinavia and Finland in geology and physiography.

Between the pre-Cambrian and the Pleistocene no formations are known, and Coleman suggests that the area may have been dry land

throughout the whole course of geologic history since pre-Cambrian times.

Coleman goes on to say:

Much of the southern shore appears to be a true igneous gneiss often of a pink color, but in the north, eruptive gneisses are relatively uncommon, seldom cover a large area, and the pink color is wanting. Whether pink or gray, the true gneisses are essentially foliated granites made up of feldspars, quartz, and dark mica. In the few sections studied under the microscope the feldspars are seen to be chiefly orthoclase or microcline, with a subordinate amount of plagioclase having a small extinction angle (oligoclase). The quartz often shows strain shadows and in some specimens porphyritic feldspars are tailed out into augen, showing that the rock had undergone shearing strains.

At one place lit-par-lit injection was seen as well as later dikes of pegmatites or granites. Basic rocks are also abundant, many having the composition of quartz diorite schist. Some rocks collected as average gray gneisses turned out to be gneissoid norites. Typical norites, consisting of nearly equal parts of plagioclase and hypersthene with a considerable amount of magnetite, also occur.

The anorthosite containing the famous labradorite of Paul Island and the adjacent islands, and parts of the mainland, is of the same age as the granite gneisses.

Following these are thick beds of sedimentary rocks now metamorphosed, which have been paralleled with the Grenville series of Ontario, though crystalline limestone, the typical rock of the Grenville series, occurs only sparingly. The gneisses are usually garnetiferous. Many of the gneisses are so siliceous that they may with equal propriety be called garnetiferous quartzites. Feldspars are only occasionally recognizable.

The garnets seem to be of more than one variety, ranging from pale rosy crystals in the more quartzose rocks to dark brownish red varieties in the more basic rocks.

Graphite is abundant.

A later sedimentary series, probably 8,000 feet thick, comes above the Grenville series. All these lower beds are pierced by innumerable black dikes, some up to 100 yards in width. These dikes are of ophitic dolerite, but usually much weathered.

Above these more ancient rocks, pierced by the dikes, come other thick beds of sediment now converted into slates, with occasional sandstone and breccias; impure dolomite with a layer of amphibolite. This is the Ramah series.

The Mugford series, also sedimentary, come above the Ramah and consists of dark slate, chert, quartzite and sandstone and limestone, altogether about 900 feet thick. These contain basic eruptives, tuffs, and agglomerates.

Taken altogether, Labrador seems a more promising area, as far as the gneisses and foliated granites are concerned, from which could have been derived the necessary types of minerals which have been enumerated above as making up the sedimentary rocks of the pre-Cambrian and Paleozoic systems round the North Atlantic. Of the large suite of basic rocks and metamorphosed sedimentary rocks given by Coleman, however, little or no trace is found in the sedimentary rocks with which I am dealing, and for that reason it appears evident that Labrador, as far as is at present known, can not be regarded as a land mass which would contribute almost exclusively granite material.

THE SIZE OF THE AREA

The present-day Mississippi, with its tributaries, drains an area the size of Europe with the exception of Russia, Norway, and Sweden, and its delta covers an area of 12,300 square miles. The delta is advancing about 262 feet per annum at the Passes, and the amount of detritus brought down each year would build a prism 268 feet high on a base having an area of 1 square mile. The belt of clastic deposits surrounding the North Atlantic and derived from the ancient land mass would make up many such deltas as that of the Mississippi, and correspondingly must the land mass from which these were derived have exceeded that which has so far been laid under contribution for the Mississippi Delta. Vertical as well as horizontal dimensions must be considered; since if we regard as reasonable that the major portion of the clastic material of each of the named periods was derived at first hand from the parent rock, then this necessitates the same area being subjected to denudation at many successive periods, and this is easier to conceive of as due to repeated elevations of the old lands.

THE POSITION OF THE AREA

The evidence which I have given of the distribution of the resulting sediments points conclusively to the land mass being situated in what is now the North Atlantic region. Summing up all the evidence, it appears to me convincing that the present land masses surrounding the North Atlantic, even when brought together as has been suggested by Wegener and others, could not give us all that is required in the type and amount of sediment, and therefore either these lands must themselves be much extended beyond their present boundaries and these extended areas consist of different materials from those which characterize the present fragments, or there was an actual continental area occupying the whole of the present North Atlantic which has since broken up and foundered.

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THE METEORITE CRATERS AT HENBURY, CENTRAL AUSTRALIA¹

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[With 3 plates]

In the early part of 1931 public interest in South Australia was stimulated by the fall of the Karoonda meteorite² on November 25, 1930, and its subsequent discovery by an Adelaide University party led by Prof. Kerr Grant. In consequence of this Professor Grant was informed separately by Mr. B. Bowman, of Tempe Downs, and Mr. J. M. Mitchell, of Oodnadatta, that fragments of meteoric iron were to be found surrounding several craterlike depressions near Henbury cattle station in Central Australia. The number of craters was variously described as three and five.

Prof. Kerr Grant placed this information before the authorities of the South Australian Museum, and Prof. Sir Douglas Mawson, the honorary mineralogist to that institution, immediately suggested that the museum should investigate the reports. The author consequently was commissioned by the museum authorities to make a preliminary survey of the area. In this he was fortunate to be assisted by Mr. F. L. Winzor, of the chemistry department, University of Adelaide.

LOCALITY

Henbury is situated on the dry watercourse of the Finke River about 120 miles, by motor, from Rumbalara railway station. This distance is shortened by about 10 miles if the journey is made by camel, the usual means of transport of the country. The meteorite locality (fig. 1) is situated 7 miles west-southwest of Henbury and adjacent to a strong ridge which runs in an east-west direction and which forms an outlying spur of Bacons Range. The locality is known locally as the "Double Punchbowl," due apparently to the two largest craters being in close proximity.

¹ Reprinted by permission from the *Mineralogical Magazine*, vol. 23, No. 136, pp. 19-32, March, 1932.

² Grant, K., and Dodwell, G. F., *Nature*, vol. 127, pp. 402, 631, London, 1931. (*Min. Abstr.*, vol. 5, p. 15).

Geologically, the Henbury area consists of Ordovician sediments, mostly sandstones and quartzites, which are known as the Larapintine series, the nomenclature being derived from the aboriginal name for the adjacent Finke River. Characteristic Ordovician fossils are found in these beds at Tempe Downs, some 60 miles distant. At Henbury wide alluvial plains are interrupted by ridges and hills which generally consist of the more resistant quartzites.

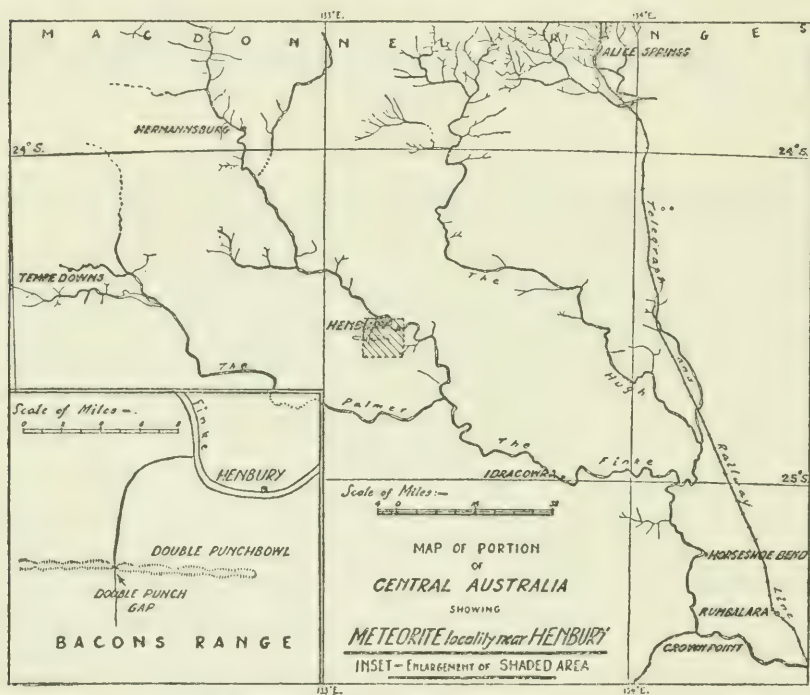


FIGURE 1.—Sketch map of the locality

THE CRATERS

The view of the craters from the plain is decidedly unimpressive (pl. 1, fig. 1), so much so that they could very easily escape the notice of an observer who did not approach quite close to them. The only indication of anything unusual is the presence in one of them of green trees, the tops of which are prominent in a region where, owing to the aridity, green vegetation is extraordinarily scarce.

The number and size of the craters were found to be much greater than was anticipated. Within an area of half a mile square at least 12 probable craters were located (fig. 2), varying in size from the smallest with a diameter of about 10 yards up to the largest of which the longest diameter is about 220 yards from rim to rim. The author believes that a more detailed survey over a wider area will probably lead to other craters being located.

There is one extremely useful point which greatly aids in the locating of the smaller craters, and also in their identification in cases when the crater walls have been removed by erosion. That is the presence of mulga trees. Mulgas are, in this area, practically confined to the watercourses, which, although generally dry, occa-

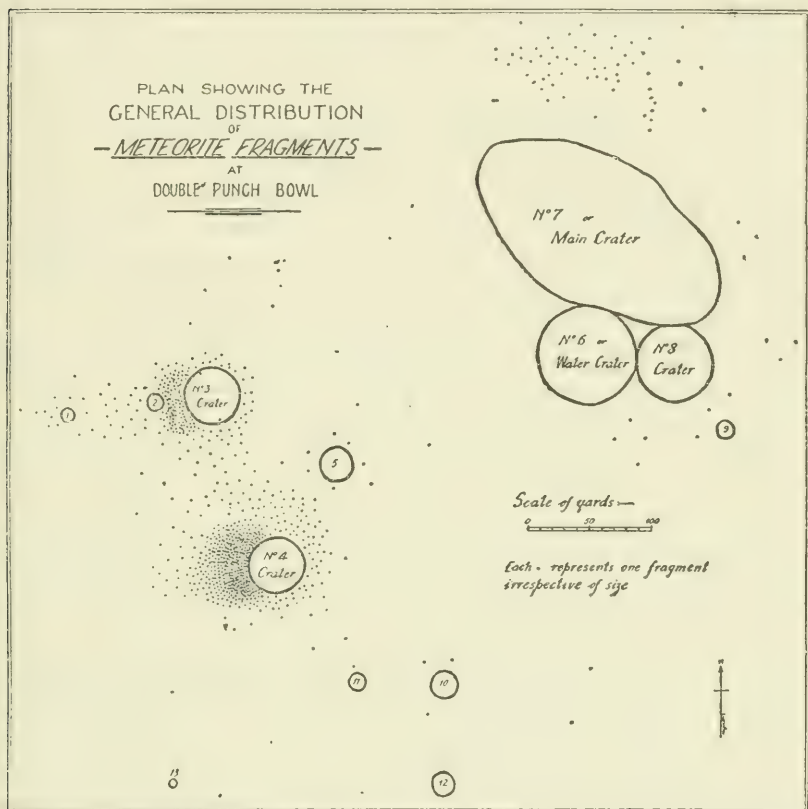


FIGURE 2.—Plan showing the general distribution of the craters and of the meteorite fragments around them

sionally flow after rain. The craters, however, almost invariably contain a clump of mulgas. This is due to the concentration in the center of the crater of any rain water falling within the crater walls. The inward wash of rain has naturally filled up a great deal of the central depression and the finer sediment has formed a highly impervious surface after the nature of a "clay pan." Water is thus preserved in the crater for a much longer period than outside the walls.

The greatest interest was attached to the two largest craters, which may be called the Main Crater and the Water Crater (Nos. 7 and 6). Viewed from the outside, a very gentle slope rises up to

the brim and in appearance entirely resembles one of the low elevations which foot the adjacent quartzite ridges. However, as soon as the rim of the Main Crater is reached the effect is startling. A huge depression is seen, 50 to 60 feet deep and of oval shape, being about 220 yards in its longest axis and 120 in its shortest. Mulga trees and grasses cover the floor, which consists of cracked mud cakes resembling the floor of a "clay pan," and which apparently retains water for some time after rain (pl. 1, fig. 2). The crater walls are generally steep near the summit (pl. 2, fig. 1), but at lower levels slopes of talus reach more gently in toward the center of the depression. The height of the walls from floor to rim is on the average from 40 to 50 feet, but it is evident that they have formerly been considerably higher than they are at present. The walls themselves consist for the most part of shattered and crushed fragments of sandstone and slaty rock varying in size from the finest powder up to large blocks several cubic feet in volume. In one or two places slaty rock, very much shattered, has the same dip as the country rock and seems to be in situ in the walls. This point is of interest and will be mentioned later.

Adjacent to the Main Crater and lying to the south of it are two other craters, the larger of which may be called the Water Crater. A watercourse having broken through the walls, an inflow of water evidently results after rain. This water is apparently preserved for some weeks after the rain has fallen. This has led to the greater development of vegetation, and both mulgas and other acacias have grown in this crater to a size unusual in the area. One or two trees (apparently *Acacia salicina*) have a height of about 45 feet, the diameter of the trunk being up to 21 inches. In shape the Water Crater is roughly circular with a general diameter of about 80 yards. The walls vary in height from 12 to 25 feet, reaching the maximum at that point where they divide the Main Crater from the Water Crater. The general description of the walls of the Main Crater may be applied to the walls of this and all the other craters.

A summarized description of the craters follows (fig. 2):

No. 1. Somewhat indefinite owing to the complete removal by erosion of the crater walls. An isolated circle of mulgas with a "clay pan" floor, together with the presence of meteoric iron fragments surrounding it, leaves little doubt in the author's mind that this is a former crater. Probably originally circular, with a diameter of possibly 25 yards.

No. 2. Similar to No. 1, but somewhat larger. Circular, with diameter of possibly 30 yards.

No. 3. A very well-defined crater, circular, with a diameter of about 45 yards. General height of walls 10 to 18 feet. About 160 iron fragments, many being very small, were found surrounding this crater, and of this number about four-fifths were lying to the west. A large jagged piece, weighing 13 pounds was found within the crater walls. Another large mass was found in a position

where a watercourse had at one point broken through and washed away the crater wall.

No. 4. Very similar to No. 3. Circular, diameter about 45 yards, general height of walls 10 to 20 feet. In the immediate neighborhood of No. 4 about 500 fragments of various sizes were found. Of these nearly 400 were on the west side of the crater. As noted below, about 100 of these were lying within an area of 6 by 6 feet.

No. 5. Circular, diameter 25 yards, low walls. Boring in the "clay-pan" floor showed a depth of 8 feet of fine soil before coarse rock fragments prevented further sinking.

No. 6. The Water Crater. Roughly circular, with diameter of 80 yards. Height of walls 12 to 25 feet, the highest part being that which divides this crater from the Main Crater. A watercourse has broken through the wall on the south side, water being preserved in the pan for some time after rain. This crater contains mulga and other acacia trees, the latter reaching a height of 45 feet.

No. 7. The Main Crater (pl. 1, fig. 2; pl. 2, fig. 1). Oval in shape, with its principal axes 220 and 120 yards from rim to rim, and 170 and 70 yards across the floor. The peculiarity of shape is possibly due to two large masses landing simultaneously and in close proximity. Height of walls averages 40 to 50 feet. Fragments of iron mostly on north side.

No. 8. Well-defined, circular, diameter 55 to 60 yards. Height of walls varies from 3 to 15 feet, being greatest where No. 8 is divided from the adjacent Main and Water Craters.

No. 9. Ill-defined and doubtful; the topography, however, suggests a small crater.

No. 10. Like Nos. 11, 12, and 13, is situated on a low sandstone ridge to the south of the main craters and to the north of the prominent ridge of siliceous breccia previously mentioned as a spur of Bacons Range. No. 10 is circular, with a diameter of about 20 yards; low walls. It is about south-southwest of the main group of craters.

No. 11. On ridge, circular; diameter about 15 yards.

No. 12. On ridge. A very well-defined circular crater sunk into side of ridge, the walls reaching 12 or more feet on the highest side; diameter 20 yards. (Pl. 2, fig. 2.)

No. 13. Rather indefinite, but there can be very little doubt that this is a crater; diameter about 10 yards.

METEORITE FRAGMENTS

A great number of metallic meteorite fragments are scattered over a wide area (fig. 2). Those collected are of all shapes and vary in weight from a fraction of an ounce up to 52½ pounds. The shape of many of them suggests that they were fragments torn or scaled off a large mass, whereas others seem to have fallen as complete units. This, together with the fact that a number of craters were located, suggests the extreme probability that many of the fragments were torn off large masses immediately before or during impact with the earth and that others fell at the same time but separately. It was, of course, owing to the impact of the largest members of this meteoric shower that the craters were formed.

It was extremely noticeable during the collection of material that in many instances a number would be found within an area of perhaps a square foot or so, the surrounding area being practically devoid of fragments. In an area of 6 by 6 feet near crater No. 4 over a hundred fragments were collected.

These facts are suggestive of the breaking up of large masses. The greatest number of fragments were found surrounding craters Nos. 3 and 4 and generally to the west of them. Many of the larger pieces were found at some distance, perhaps 100 to 200 yards from the craters, whereas the small fragments were mostly close to the crater's edge. Very few were found within the walls of any of the craters. Around the group of large craters (Nos. 6, 7, and 8) fragments were notably scarce, except on the northern side. This, how-

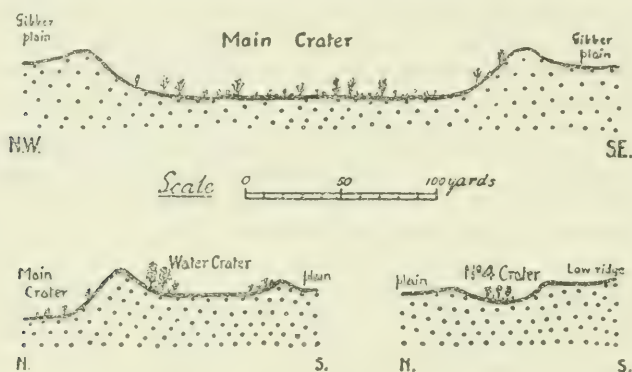


FIGURE 3.—Sections through the craters

ever, is easy to understand. Immediately after the fall of the meteoric material the crater walls must have been very considerably higher than they are now and fragments of meteorite may have covered the existing land surface. Erosion has, however, since removed material from the walls and it has washed downwards, both inwards into the craters and outwards on to the plain. The material so removed has covered up most of the meteoric fragments except in such places where a slight alteration of the drainage has again uncovered them. It was noticeable that most of the fragments found near the main craters were in shallow watercourses.

ABSENCE OF POSITIVE EVIDENCE OF IRON MASSES IN THE CRATERS

None of the craters showed any evidence, at the surface, of containing a large mass of meteoric iron. Further, the presence of fragments of iron within the crater walls was rare. This, of course, was to be expected. Certain simple observations were made, therefore, in an attempt to locate masses of meteoric iron in the craters. A light hand-boring tool was used in one of the smaller craters.

Crater No. 5 was considered to be the most suitable for this purpose. A hole to the depth of 8 feet was sunk through fine loamy soil. At this depth rock fragments, apparently washed inwards from the walls, prevented further sinking. This showed that the small crater No. 5 had originally been at least 8 feet deeper than it now is. If any meteoric mass has penetrated to a depth of more than 8 feet below the present floor of a small crater like No. 5, the depth to which such a mass has penetrated below the larger craters must be very considerable.

An experiment was also made to see if a compass needle showed any deviation on approaching and passing the Main Crater. Traverses were made with this end in view, but the prismatic compass used gave results which could not be considered beyond the limits of experimental error.

Although these observations gave results which can only be considered as negative, the author believes that further work along these lines should be proceeded with as soon as possible. In such a case as this the use of geophysical methods seems to be ideally suited. If, as at the great Meteor Crater at Canyon Diablo in Arizona, magnetic methods prove to be somewhat unsatisfactory, it is highly probable that good results would be obtained by the use of gravimetric, seismic, or electrical methods.

EFFECTS OF IMPACT

The excavating effect of the fall of a large meteoric mass is of course self-evident, and the intense shattering and crushing of the surrounding country rock are only to be expected. The walls in all cases consist of unconsolidated fragmentary rock material varying in size from the finest powder up to large masses several cubic feet in volume. The effects of shearing stresses are also to be noted in many specimens.

Besides the formation of the 12 or more craters mentioned, the impact of the meteoric bodies with the earth has left traces of other effects which are extremely interesting. One of these phenomena is shown particularly well by crater No. 3. Radiating outwards into the plain from the crater walls can be seen five or six low ridges of sandstone. These suggest "dikes" of a hard rock which has resisted erosion more successfully than the surrounding country rock. They consist, however, of sandstone which is apparently identical with that to be found anywhere in the neighborhood. The "ridges" are only a few inches higher than the surrounding surface of the plain, but consisting as they do of small blocks of sandstone, of which the surface is blackened due to weathering, they are easily distinguished

from the prevailing reddish color of the surrounding gibbers.³ These "dikes" radiating outward from the crater immediately reminded the author of the "percussion figures" obtainable in mica under suitable conditions. Although traces of similar ridges were found around some of the other craters, particularly No. 4, none were as well defined as those described around No. 3. The length of these ridges varied considerably, but one could perhaps mention 30 yards as an average distance from the crater rim that a "dike" could still be traced on the plain.⁴

Another point of extreme interest was the discovery on the plain to the north of the Main Crater of black glassy material greatly resembling the glass of fulgurites. This is seen in some specimens to be vesicular, in others to be cementing rock fragments. There is little doubt that this has been formed by the fusing of the country rock by the enormous heat of impact of the meteorite. It is a point of interest that glassy siliceous matter apparently of similar origin has been found at the great meteorite crater at Canyon Diablo in Arizona.

DIRECTION OF FALL

Until the position of any iron masses buried in the craters has been located, the direction of fall of the meteoritic bodies must be more or less a matter of conjecture. There is, however, one point which may give some indication of the direction in which the bodies were traveling. Notes were made as to the general position of all meteoritic specimens collected. From this it was seen that the material was generally concentrated on the western side of the craters (fig. 2). This was particularly noticeable in the case of craters Nos. 3 and 4. Around these craters there seemed to be no indication that such factors as prevailing winds or surface drainage had favored the uncovering of meteoritic material on one side more than the others.

This fact is subject to two interpretations depending on whether the majority of the fragments were formed by the impact having a shattering effect on the larger masses, or whether the fragments had existed separately for some time before landing. If the former supposition is correct, one would expect that the fragments had been deposited or "splashed" on the farther side of the crater; that is, the meteoritic bodies possessed an east to west movement. If the latter is the correct supposition, one would expect that the smaller bodies, not possessing the momentum of the larger, would be im-

³ Gibber, aboriginal Australian for a large stone or boulder.

⁴ Some of the craters of the moon (e. g., Copernicus) show somewhat similar radiating ridges. This may, perhaps, lend some support to the theory that the lunar craters are of meteoric origin.

peded to a greater extent by air resistance, and would thus fall short of the larger masses. This would then suggest a movement from west to east.

It is, of course, difficult to realize how a huge mass of iron would behave under the conditions which must have prevailed when the meteorite landed, but one would expect that the impact would cause the bodies to be at least partly shattered. This idea is supported by the shape of many of the fragments. The absence of the minute "pitting" over the whole or part of the surface of a great number of the fragments also suggests that the period of their separate existence must have been a very short one.

AGE OF THE FALL

Judged from human standards, the age of the fall must be considerable. There are many indications that it is by no means recent, but one can not as yet make any positive determination of its age. Summarized, these indications are:

(1) The complete oxidation and disintegration of certain of the iron fragments. These and other geological processes proceed with extreme slowness in a climate of such aridity. The average annual rainfall for the locality is probably about 6 inches. Some fragments were found which consisted entirely of sealy ferric oxide.

(2) The presence of fully grown mulga and *Acacia salicina* trees would put a certain minimum on its age. The author believes, however, that generations of trees have lived and died in the craters since the meteoric fall. The trunks of many dead mulgas are to be seen everywhere, some apparently of great age. The mulga is a notably slow-growing tree.

(3) Inquiries from aborigines of the district gave negative results. None of them had any ideas as to the origin of the craters. If the fall had taken place since the human occupation of the area, one would have expected accounts of such a notable happening to be handed down from generation to generation, and that also the locality would be regarded with superstitious awe. The aborigines, however, showed no interest in the craters.

(4) In the walls of the Main Crater some shattered slaty rock has the same dip as that of the surrounding country rock and may possibly be in situ. This is several feet higher than the general level of the plain, and may indicate that the level of the plain has been reduced by several feet since the formation of the crater, which in such a climate would require a very long period of time. The rock in situ in the crater walls would have been protected from erosion by the superincumbent layer of fragmentary material which formed the upper part of the previously higher walls. The occur-

rence of such rock in the walls is, however, perhaps accidental; i.e., it may have been thrown up by the impact and is not in situ at all.

It will be seen that the age indications are very vague indeed. The author is, however, of the opinion that the fall took place a very long time ago and that the age of the craters must be reckoned in terms of thousands of years.

CONCLUSION

This description would not be complete without some reference to the meteorite craters at Canyon Diablo (or Coon Butte) in Arizona, and near the Tunguska River in Siberia. The Canyon Diablo Crater is, of course, much larger than the largest at Henbury, being some three-quarters of a mile in diameter and with a depth of 570 feet from floor to rim. There are, however, many points of similarity between the two occurrences. Doctor Merrill's general description⁵ of the nature of the Canyon Diablo Crater could easily be applied to the larger ones at Henbury with but few modifications. Other notable points of similarity are the nature and occurrence of the iron fragments and the presence of fused country rock. Dissimilarities which may be particularly noted are the large number of craters in Central Australia compared with the single large one in Arizona; also the oval shape of the main crater at Henbury.

Fewer details are available concerning the craters in Siberia. Apparently the largest crater is 150 feet in diameter and about 12 feet deep, and it is interesting to note that digging in one of these craters to a depth of 30 feet failed to reveal any meteoric material. The largest of the Siberian craters is thus much smaller than the Main Crater at Henbury, so that it is possible that meteoric material at Henbury may be buried to a very considerable depth. A bore sunk in the Canyon Diablo Crater reached a hard mass at about 1,376 feet. It is, however, still uncertain that this is the main bulk of the meteorite.

Bearing these facts in mind the author would suggest that further work at Henbury should obviously be along the following lines:

(1) That a wider survey of the area be made. Owing to difficulties of transport and lack of the necessary time only a comparatively small area was examined. The author believes that a wider survey may lead to the discovery of more craters, some of which may be of considerable importance.

(2) That use be made of geophysical methods in an attempt to locate the position of masses of meteoric iron in any of the craters. The locality, the type of country rock, and the nature of the material to be located seem most ideally suited to the use of such methods.

⁵ Merrill, G. P., *Smithsonian Misc. Coll.*, vol. 50 (Quarterly Issue, vol. 4), p. 461, 1908.

(3) That if the position of a mass of iron be located by geophysical means, boring operations could then be proceeded with advantageously. Boring or drilling would certainly be of great value in prospecting the main craters. In some of the smaller ones it is possible that the meteoric material might be revealed by actual digging.

These notes are merely the record of a preliminary survey and the author believes that work along the lines suggested will lead to results which will be of interest to the world in general and particularly to the world of science.

Acknowledgments.—The author wishes to record his sincere thanks to the authorities of the South Australian Museum for providing the opportunity for him to visit Henbury; to Profs. Sir Douglas Mawson and Kerr Grant for their enthusiastic support and advice; and to Mr. F. L. Winzor for his invaluable help and company during the stay at the meteorite locality.

ADDENDUM BY L. J. SPENCER

After reading the typescript of Mr. Alderman's most interesting paper, I was rather surprised to find that the meteorite craters he describes are marked on The Times Atlas (London, 1922, pl. 105). Between Henbury and Bacons Range they are indicated as a small round hill in exactly the position shown on Mr. Alderman's sketch map (fig. 1). The latitude and longitude of the spot are $24^{\circ} 34' S.$, $133^{\circ} 10' E.$ This is about 50 miles south of the MacDonnell Ranges in the very center of Australia. After Mr. Alderman's visit to the locality in May, 1931, a visit was made in June by the brothers R. and W. Bedford and Mr. B. Duggin, from the Kyancutta Museum at Kyancutta, South Australia, which involved a journey by motor truck of about 3,000 miles. Of the material then collected Mr. R. Bedford has sent to the British Museum a large series of 542 complete pieces of the meteoric iron ranging in weight from 3.4 grams to $170\frac{1}{2}$ pounds ($77\frac{1}{2}$ kg). There are large pieces weighing 11,445 and 6,550 grams and several of about 2 kg, but the majority are small shelly and jagged pieces. The total weight of the 542 pieces is 321 pounds (146 kg). In addition, about 20 pounds of "iron shale" and fused rock fragments were sent; also excellent sketches and photographs made by Mr. R. Bedford of the craters. The Adelaide party collected 800 pieces of the iron, and the Kyancutta party 550.

It is quite evident that at these craters there was a large shower of many separate masses of meteoric iron. But the presence also of the laminated "iron shale" in pieces up to several pounds in weight (the largest piece sent by Mr. R. Bedford weighs 1,668 grams) and

up to $5\frac{1}{2}$ cm in thickness indicates that the iron has suffered considerable oxidation by weathering. Many of the smaller pieces of iron are flaky and shell-like with convex and concave surfaces, and they often show fantastically twisted forms. In one or two cases such a shell-like flake is only loosely attached to a larger piece. It therefore seems probable that many of the smaller pieces are the result of the breaking down of larger masses by oxidation.

From my examination of the 60-ton Hoba meteorite, buried in situ with its enveloping zone of "iron shale," I am convinced that the concave and pitted surfaces so commonly shown by iron meteorites are the result of subsequent weathering rather than of burning during the brief flight through the atmosphere. This pitting is no doubt due to the decomposition of the particles of troilite (FeS) scattered through the iron. The surface of the Henbury irons, with a skin of glazed limonite, is quite different from that of the few iron meteorites which have been actually observed to fall.

The presence of the "iron shale" supports Mr. Alderman's conclusion that the fall of the meteorite took place ages ago. Mr. R. Bedford is, however, of the opinion that the fall is comparatively recent. On his return journey he interviewed, at Oodnadatta, Mr. J. M. Mitchell, a local prospector, who had known of the masses of iron 12 years ago. Mr. Mitchell asserted that the old blacks would not camp within a couple of miles of the place, and that they called it "chindu chinna waru chingi yabu," meaning "sun walk fire devil rock."

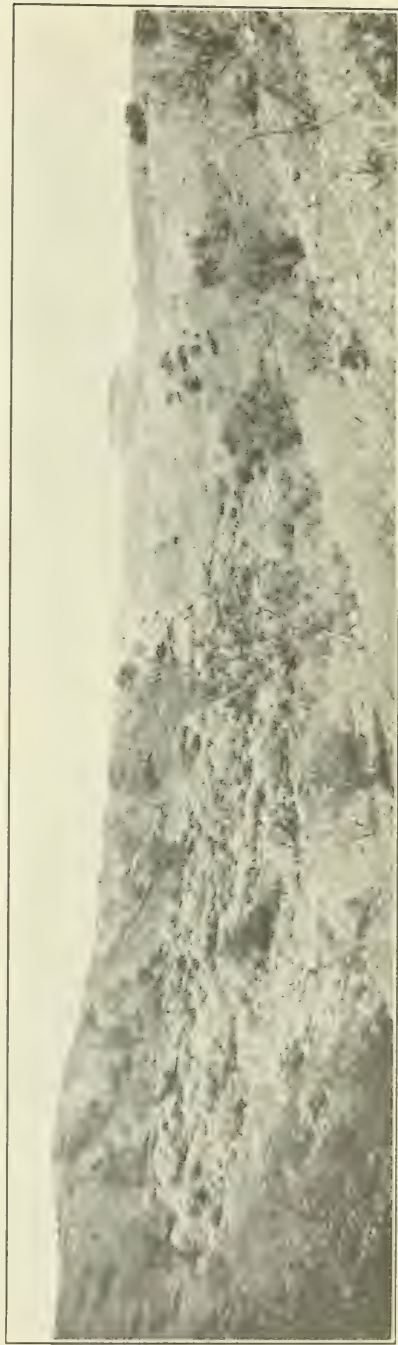
An etched section of the iron shows well-marked Widmanstätten figures of the medium octahedrite type. Besides kamacite, taenite, and plessite, there are a few minute specks of troilite. The kamacite bands, instead of being straight, are wavy and in places much curved and distorted. During the process of etching no straight and definite Neumann lines were detected, but the kamacite bands are marked by wavy lines and an irregular network of cracks. This would indicate a disruption of the mass, which may have taken place at the time of fall or at some earlier period.

Mr. Alderman's paper is a valuable contribution to the scanty knowledge of the problematical meteorite craters; and in the case he describes the association of meteorites with the craters could scarcely be fortuitous. Meteorite fragments have been also found around the single craters of Canyon Diablo (Arizona) and Odessa (Texas), but none near the craters of Tunguska (Siberia) and Kaali (Esthonia).⁶ Around the 60-ton Hoba (Southwest Africa), the largest known meteorite, there is no sign of a crater.

⁶ Min. Abstr., vol. 4, pp. 427-428, 1931; vol. 5, pp. 16-17, 1932.



1. View from the south of craters Nos. 6, 7, and 8. The full extent of the Main Crater (No. 7) is hidden by Nos. 6 and 8. The larger trees are in the Water Crater (No. 6)



2. Panoramic view of the Main Crater (No. 7)

METEORITE CRATERS AT HENBURY, CENTRAL AUSTRALIA



1. Radiating ridges around No. 3 Crater. One ridge extends from camera toward edge of crater. Mr. Winzor is standing on another such low ridge



2. Inside wall of the Main Crater. Over the edge are seen the tops of the trees in the Water Crater
METEORITE CRATERS AT HENBURY, CENTRAL AUSTRALIA



1. View inside crater No. 12, showing shattered blocks of sandstone in the crater walls



2. Typical fragments of the meteoric iron. (With scale of inches)

METEORITE CRATER AND METEORIC IRON, HENBURY, CENTRAL AUSTRALIA

SOME GEOGRAPHICAL RESULTS OF THE BYRD ANTARCTIC EXPEDITION ¹

By LAURENCE M. GOULD

University of Michigan

[With 9 plates]

During the course of my duties as geographer and geologist of the Byrd Antarctic expedition I had the opportunity to make a special study of three major features—the Rockefeller Mountains, the segment of the Queen Maud Mountains charted by the geological party, and the Ross Shelf Ice. It is with these features that we are here concerned.²

THE ROCKEFELLER MOUNTAINS

Of necessity the major part of the expedition's first summer in the Antarctic was consumed by the business of establishing permanent quarters—Little America. Commander (now Rear Admiral) Byrd did, however, find time to make a number of flights eastward over and beyond King Edward VII Land. On the first of the flights, January 27, 1929, he discovered a new range, which he named the Rockefeller Mountains. In view of the fact that hitherto the only known land in this sector of the Antarctic was the scattered group of low-lying peaks known as the Alexandra Mountains, this discovery was of potential importance, and it was most desirable to make of it at least a brief reconnaissance during our first summer. Unfortunately the season had become rather far advanced before it was practicable to undertake this venture. On March 7 Bernt Balchen, Harold June, and I took off for the mountains. After a flight of 2 hours and 10 minutes in a direction a little north of east and against a fairly strong head wind we landed near the southern extremity of the group. We were out early in the morning; but the wind began to rise as the day drew on, and about noon we had to stop our surveying. A lull in

¹ Copyright, 1931, by the American Geographical Society of New York. Reprinted by permission from the *Geographical Review*, vol. 21, No. 2, April, 1931.

² For a general summary of the work of the expedition, see Joerg, W. L. G.: *The Work of the Byrd Antarctic Expedition 1928–1930*, American Geographical Society, 1930. Also *idem*, *Brief History of Polar Exploration Since the Introduction of Flying*, Amer. Geogr. Soc. Special Publ. No. 11, 2d ed., pp. 11–20, 1930.

the late afternoon enabled us to make our first ascent of the mountains.

For the next three days and nights we were occupied in a strenuous struggle with the wind. On the morning of the 13th calm though not clear weather permitted a return to surveying. We climbed the peaks near by, completed our triangulation, and collected a fairly representative number of rock specimens. On the 14th the wind came on stronger than ever. All precautions and efforts to save the plane were futile. In the late evening a sudden gust tore the plane loose from its moorings, lifted it bodily into the air and literally flew it tail foremost for more than half a mile and dropped in onto the ice a total wreck. On the 18th Commander Byrd with Dean Smith and Malcolm Hanson arrived to bring us back to Little America. June and Balchen returned to Little America with Smith, while Commander Byrd, Hanson, and I remained at the mountains to be picked up on a second flight on the 22d.

To anyone expecting a great mountain range the Rockefellerers are rather disappointing. They are a group of low-lying scattered peaks and ridges almost completely smothered with snow. Many of the smaller masses are completely covered and appear only as bulges in the otherwise almost level surface, and even the largest mountains show but scant exposures of bare rock. The peaks and ridges range in height from about 500 to slightly over 2,000 feet above sea level. They begin roughly in latitude $78^{\circ} 14'$ S., longitude $155^{\circ} 15'$ W., and extend northeastward as a crescentic-shaped group with the crescent opening toward the west. Their most northern limits are in latitude $77^{\circ} 35'$ S., longitude $153^{\circ} 5'$ W.

From the air the bare rock surfaces looked so pink and of such a solid uniform color that I at first thought the mountains were composed either of trap rock or sandstone. Such was not the case; the main body of rock is a coarse-grained pink granite. A few pegmatite dikes and veins have intruded the older granite. In places it is also shot through with dikes of gray granite and pink granite differing from the main mass primarily in structure only. There are a few narrow quartz veins; and these, like the pegmatites, are barren of any interesting or important mineralization.

In sheltered places bits of gray lichens and a greenish moss-like growth were found. Unfortunately our specimens of the latter were lost when the plane was blown away, and we were not able to find any more on further search.

There is apparently a great deal of melting about these mountains during the warmer months. In many places their upper slopes are encased in a thin rind of blue ice, while great fields of ice formed from the freezing of slushy snow extend in places from 7 to 10 miles

from the mountains. Curious circular patches of darker ice from a few inches to 2 or 3 feet across, caused by rocks burying themselves through absorbed heat during the summer months, give to these fields a freckled appearance. A real lake, about 3 miles in diameter, which at the time of our visit was frozen into solid blue ice, had been formed on the southern side of the mountains, evidently by the accumulation of melt water from the higher slopes.

We found no crevasses indicating any glacier-like movement around the mountains; probably their tops were formerly overridden by ice, but only a mildly erosive effect resulted or else weathering has been amazingly rapid here. We looked in vain for such evidences as scratches, striations, and erratics. The terrain about the mountains averages not more than 300 feet above sea level; and one gets the impression that, were the snow to disappear, what we now call a mountain group would become an archipelago.

So far as the origin of these mountains is concerned, their relief is not due primarily to tectonic disturbance. They appear, rather, to have been left by the erosion of materials around them—peaks and ridges of circumvallation. I believe the Alexandra Mountains to the northward, to which the Rockefeller appear to be at least petrographically related, belong to the same integral land mass and likewise owe their relief primarily to the forces of erosion.

No analysis or petrographic studies of the rocks brought back from the Rockefeller Mountains are yet available. These may establish some positive relationships with the rocks across the Ross Sea. I think this is doubtful. At any rate these mountains show no definite structural affinities with other known lands in the Antarctic.

THE QUEEN MAUD MOUNTAINS

The plans³ for our geological reconnaissance of the Queen Maud Mountains were made in the light of what was believed to be the geographic outlines of this sector of the Antarctic as revealed by Amundsen. He had reported appearance of land between latitudes 81° and 82°, roughly in longitude 159° W. He had further believed that the Queen Maud Mountains trended southeast from Axel Heiberg Glacier, crossing the continent only some 140 miles from the pole itself. Finally, he indicated a great highland beginning in the Queen Maud Mountains in about latitude 85° 45' S., longitude 160° W., extending thence northeast at least to 84°, and possibly connecting somewhere with the appearance of land between latitudes 81° and 82°. This highland he called Carmen Land.⁴

³ Details of the preparations and the incidents of the trip itself are described in chs. 11 and 17, the latter contributed by the writer of Admiral Byrd's narrative, *Little America*, New York, 1930.

⁴ See Joerg, *Work of the Byrd Antarctic Expedition 1928-1930*, p. 56, footnote.

The geological party planned to do specifically three things. First, to sledge directly southward from Little America to the foot of the Queen Maud Mountains and there ascend Mount Fridtjof Nansen with a view to getting a cross section of the range; second, to sledge eastward from Axel Heiberg Glacier along the foot of the Queen Maud Mountains to their junction with the supposed Carmen Land—this seemed vastly important, for Amundsen's plotted position of Carmen Land indicated a highland running practically at right angles to the trend of the main Queen Maud Mountains, a curious and unnatural-seeming relationship; third, on the way back toward Little America to make a detour eastward to investigate the land indicated by Amundsen between latitudes 81° and 82° .

On its way southward the supporting party was first to pass to the westward of this supposed land. They failed to see it. The geological party, which followed soon after, found no evidence of it; and finally, on the flight to lay a cache of oil and gas at the foot of Axel Heiberg Glacier preparatory to the polar flight, Commander Byrd and his party corroborated these observations. Our plans were then altered to the extent that we did not leave the trail homeward bound. Otherwise they were carried out in their entirety and with more time at our disposal than we had hoped to have.

THE SLEDGE JOURNEY OF THE GEOLOGICAL PARTY

To accomplish so long a journey it was necessary for us either to make a preliminary depot-laying trip or to have an additional unit help us move our heavy loads some distance southward from Little America. The latter plan was adopted for conservation of time. The so-called supporting party, composed of Arthur Walden, leader; Christopher Braathen, Joe de Ganahl, and Jack Bursey, preceded us for 200 miles and established depots of food and fuel every 50 miles. On November 4 the geological party took its final departure from Little America. There were six of us—Norman D. Vaughan, dog driver and in general charge of the dogs; Frederic E. Crockett, dog driver and radio operator; George A. Thorne, dog driver and topographer; Edward E. Goodale, dog driver; John S. O'Brien, dog driver and surveyor, and myself as geologist and navigator.

We proceeded southward, keeping as nearly as possible on the meridian of longitude $163^{\circ} 31' W$. From Little America to the foot of Liv Glacier we passed over two features of some geographical note; otherwise this part of our trek contained little that was novel. The first matter of interest was the fact that at 25 miles south of Little America we found ourselves going up a fairly gentle slope. From an altitude of 200 feet above sea level at the station we ascended

gradually to 895 feet above sea level at 50 miles, and we were not yet on top of the hill. We had but crossed diagonally the northern end of a great gentle bulge in the shelf ice. Its axis trended southeast to northwest, and we estimated it to be at least 50 miles long. We conservatively judged that this hill must attain a height of at least 1,000 feet at its highest point. Except for this bulge there are no significant changes in level of the shelf ice between Little America and some 15 to 20 miles from the foot of the mountains. It presents on almost every hand a featureless plain of dead monotony.

There seems little question but that this hill indicates a place where the shelf ice is held up and back by land. Crevasses to the west of it and even to the southwest where we came down from its slope onto the general level of the shelf indicate that there is some movement of the ice about it.

THE CREVASSED AREA

The second area of more than passing interest in this first leg of our journey was the crevassed region between latitudes $81^{\circ} 10'$ and $81^{\circ} 17' S$. Amundsen described an eerie passage through this region, and both the supporting party and we of the geological party often found ourselves holding our breath as we threaded our way through the crevasses. As we approached this region from the north we first came upon old crevasses long since dead and now filled with snow and ice. Next we found ourselves in a region of partially filled crevasses which here and there expanded into circular depressions from 5 to 15 feet across. They were not unlike symmetrical sink holes in appearance. A few haystack-shaped mounds were noted here, but their number increased farther south where the crevasses gave evidence of being much younger. Some of these haystacks had steep sides and a beehivelike configuration. These were generally thin-skinned; and some could be broken with a ski stick to reveal a great chasm below. Apparently the circular sink-holelike depressions represent the site of these thin-skinned haystacks. The faulted-dome type of haystack with a flatter, more conical profile was present in larger numbers than the beehive type.

On the southern edge of this region we found newly formed cracks from a few inches to more than a foot in width. Camped here for the night, we soon became aware that all was not quiet around us. The ice was cracking about and under us, sometimes with detonations like distant cannon and again with sharp reports like rifles fired close by. Occasionally the tent itself would be jarred as the ice snapped. I timed these reports with my stop watch and found that they averaged one a second for about 20 minutes, when I fell asleep. When I awoke three or four hours later and again listened, I was amazed

to hear not a sound of any sort for many minutes. It appeared that even though the shelf ice is here at least 700 feet thick it was under such a great strain that even the weight of our outfit was enough to disturb its equilibrium and start it cracking. This camp was really well to the south of the very badly crevassed portion. At a later time we found ourselves camped in the midst of crevasses and chasms toward the northern edge of this interesting region. I took special notice to see if our previous experience would be repeated. It was not. We heard not a sound of cracking ice. Apparently the active movement of the ice is from the south, as the shapes of the crevasses would suggest, while the ice becomes stagnant toward the north. A study of the aerial photographs taken over this region indicates a movement from the southeast. These photographs further revealed the fact that the whole broken area is but some 75 miles in length.

Seventy miles north of the Queen Maud Mountains on our homeward way the performance described above was duplicated. There was a constant cracking of the ice all about us when we turned in, but never a sound when we woke in the morning. Here, however, were no surface indications of the great strain that the ice is under; the surface is practically level, and we found no crevasses within 15 miles on either side of this camp.

Frequently in the course of the summer we found ourselves camped among the crevasses near the mountains and even on the glaciers themselves, but in no other places than the two noted above were we thus noisily saluted.

APPROACH TO THE MOUNTAINS

From depot No. 4 at $81^{\circ} 43'$ S. we now pioneered the way, establishing depots every 50 miles. We had planned to go directly south to Axel Heiberg Glacier, but at depot No. 7 at 84° S. we changed our course 15° to the west and thus proceeded directly to the foot of Liv Glacier. From about 15 to 20 miles from the mountains the terrain departed from the generally level habit it had presented. Gentle rolls with a few crevasses began to appear. The rolls were so gentle and so far apart that I did not realize the change in surface until I looked behind to see dog teams disappearing in the hollows to reappear again on the rolls. These first undulations were not more than 10 to 20 feet high, and some must have been nearly a mile apart. But as we neared the mountains the wrinkles became more pronounced and closer together. Crevasses became more widespread, more persistent, and longer. At no other place in the course of our travels did we see a system of crevasses showing such an extensive and regular development as these below Liv Glacier. On the polar flight Commander Byrd had dropped us a number of aerial photo-

graphs that Captain McKinley had taken on the base-laying flight, one of them showing a system of crevasses so regular that we all thought this particular print had been made with a celluloid grid, with parallel lines scratched on it overlying the negative. Surely there could be no such regularly spaced system of crevasses anywhere. Instead, therefore, of altering our course to avoid them as far as possible, we plunged headlong into the most frightfully uncertain and hazardous traveling that we encountered all summer.

As we came still nearer to the mountains we were struck by the fact that the crevasses and undulations were not crescentic to the glacier outlets. They were rather so distributed as to indicate a movement from an easterly direction parallel to the range front at this place.

We camped at the foot of Liv Glacier on December 1 and on the next day attempted an ascent. For the 2 or 3 miles of the ascent these great rolls, some of which attained a height of 500 feet, still persisted right up the glacier as though it had not been there. They seemed to have triumphed over the puny glacier flow itself; without disturbing the symmetry of the rolls, it had but caused their surfaces to become crevassed. The aspect of the whole was like that suggested by the waves forced up a harbor or broad river mouth in the wake of a large vessel.

From Little America to within 15 miles of the mountains the shelf-ice surface had been one of varied soft snow surfaces where there had been apparently but little wind, to wide wind-swept areas with hard *sastrugi* as much as 3 or 4 feet high and always showing an east-southeast to west-northwest trend. But when we came close to the mountains the snow surface changed in places to a hard pebbled or rippled and icy surface. It seems that on occasion the snow becomes so soft and mushy that it is beaten up into these tiny ridges by the force of the wind. When we first experienced the föhnlike wind down a glacier from the mountains we at once realized how the temperature might be raised high enough to produce such an effect.

THE MOUNTAINS AND THEIR STRUCTURE

From some 20 miles away we began to form our first definite ideas about the mountains and the major aspects of their structure. We saw a great array of ragged, irregular, rather low-lying peaks backed up by great tabular mountain masses that towered far above them. The tabular mountains immediately suggested horsts; and the straight, even lines of at least some of the greater outlet glaciers looked to me like depressed fault blocks. A further striking impression of the mountains was the sharp clear-cut front of the whole range—a typical sharply defined fault-line scarp.

More intimate views of the mountains demonstrated that their topographic expression was a fairly safe guide to the character of the rocks that composed them. The foothills with their ragged outlines are composed essentially of a great mass of dark-colored micaceous gneisses and schists with smaller amounts of granites. In some places this older mass was shot through with younger lighter-colored granites giving to the whole a fairly bizarre striped effect (pl. 4, fig. 1). Pegmatitic dikes and veins are not uncommon, and in places barren quartz veins stand out sharply against the darker background. But taken as a whole the aspect is that of a dark-colored series of old metamorphics. Doubtless these rocks are pre-Cambrian, and wherever they constitute the mountain masses they have been eroded into ragged and angular peaks. In contrast the tabular mountains owe the regularity and evenness of their outlines to the fact that they are capped with a great series of practically

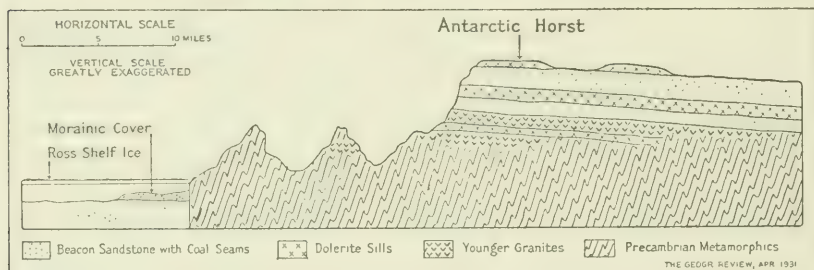


FIGURE 1.—Generalized cross section of the Queen Maud Mountains

horizontal sandstones and shaly sandstones reinforced with dolerite sills. When we came near enough we could see that the tabular mountains were tilted upward toward the north, or the outer edge, so that the plateau behind is generally lower than the scarp front (fig. 1).

A further persistent impression was that there were almost more glaciers than mountains. Every little pocket and depression along the scarp front has its individual glacier, but it is the great valley or outlet glaciers like Liv, Axel Heiberg, and the even larger ones farther east that break up the range.

MOUNT FRIDTJOF NANSEN

We had hoped to ascend Liv Glacier far enough to reach the flat-lying rocks that top the tabular mountains. We had even hoped that we could reach Mount Fridtjof Nansen this way. It was hopeless. We broke camp on the 3d of December and made our way to the foot of the glacier that takes its rise on the northwest slope of Mount Fridtjof Nansen. Here in latitude $85^{\circ} 7' S.$ and longitude $163^{\circ} 45' W.$ we established our base camp, our depot No. 8, called

Strom Camp in honor of Sverre Strom who had helped so much in our preparations for the sledge trip. Without too much difficulty we made our way up this glacier to the rocks on the northern slope of Mount Fridtjof Nansen and at two separate points about 3 miles apart climbed part way up the side of the mountain and thus got a partial cross section of these long-sought rocks.

The flat-lying sandstone series was found to rest upon the even surface of a coarse-grained gray granite. This contact zone was at 5,960 feet, and the series continues upward apparently to the very top of the mountain itself, which means that it totals more than 7,000 feet in thickness. Both the sandstones themselves and the underlying granite are intruded with dolerite sills, showing conspicuous vertical jointing and weathering into angular pinnaced forms in contrast to the softer outlines generally taken on by the sandstones themselves.

We climbed across a vertical exposure of 2,000 feet of this sandstone series. It exhibits some variation in texture and composition, but its most characteristic aspect is that of a fairly fine-grained yellow to gray, thinly banded sandstone with scattered lenses of white sandstone up to 5 feet in thickness. In more massive phases it is greatly cross-bedded. It passes into dark, even black, shaly facies which contain considerable organic matter, sufficient in places to identify the rock as a low-grade coal. From one such layer Thorne brought some fragments of a hard, bright, shiny coal which burned reluctantly when a match was applied. Of course the whole sandstone series, including the highly carbonaceous layers, has been profoundly affected by the intrusion of the dolerite sills. In the vertical section that we crossed about a third of the thickness was due to the dolerite. Looking upward, one had the impression that the sills were fewer and thinner toward the top. The sandstones are almost everywhere quartzitic, and the shaly facies have been changed in places into a hard rock with almost slaty cleavage.

There is no question that this great series of sandstones and associated rocks is at least lithologically equivalent to Ferrar's Beacon sandstone of South Victoria Land. The lower portion of that sandstone, in places at least, is Devonian and grades upward into Mesozoic with the great bulk of it comprised in the "Permian-Carboniferous" sandstones and coal measures. I have not completed the examination of the rocks we collected, so that I am not prepared definitely to state whether they contain fossils or not. I could find none in the field.

It was on our first ascent up the slopes of Mount Fridtjof Nansen that Edward Goodale found bits of gray lichens. In the course of the summer we found other growths even farther south than this, though they were nowhere prolific.

To have proceeded to any great altitude on Mount Fridtjof Nansen would have been fraught with considerable uncertainty and would have consumed a great deal more time. We had determined the significance of the flat-lying cap rocks and therefore decided to turn our attention to sledging eastward along the foot of the range toward its junction with the supposed Carmen Land, whose existence we had begun seriously to doubt. This was an eventful journey. Thorne undertook the task of mapping as we went along, an arrangement which left me free to devote my attention to the rocks and the glaciers.

EASTWARD ALONG THE FOOT OF THE MOUNTAINS

It was soon seen that the fault scarp of the Queen Maud Mountains proper proceeded almost due east from Axel Heiberg Glacier rather than southeastward across the plateau or bounding it as indicated by Amundsen. Furthermore, the proportion of old pre-Cambrian ragged mountains increased, and the tabular mountains retreated farther into the plateau and became ever lower as we proceeded eastward. Likewise, the outlet glaciers became ever larger, though without being able to handle adequately the great volume of ice that flows down from the plateau and almost smothers the mountains eastward from the one hundred and fiftieth meridian. Even so, one almost immediately discovers that the ice is much thinner here than formerly. We climbed the outlying peaks in longitude 157° and found that to heights of as much as 800 feet above the present ice level the mountain tops were rounded and polished (pl. 4, figs. 2, 3). How much thicker the ice may have been there is no way to tell. Farther eastward Supporting Party Mountain and its associated nunataks appear to have been formerly covered by the ice. This is quite different from the conditions about Axel Heiberg and Liv Glaciers. Doubtless Fridtjof Nansen, Ruth Gade, and the other high mountains in this vicinity have always been high enough partially to stem even the greatest streams of ice from inland and thus prevent such extensive glaciation of the foothills as we found prevalent to the eastward.

Supporting Party Mountain marked our farthest east: and, since its location was east of the one hundred and fiftieth meridian, we were within the sector claimed by the commander for the United States and named by him in honor of his wife, Marie Byrd Land. His claim was based on the fact that he had flown over the newly discovered land in the latitude of Little America. In substantiation we built a cairn on the top of Supporting Party Mountain and raised the flag. Inside the cairn we left a tin can containing a note

setting forth the fact that in the name of Commander Byrd we claimed the land as a part of Marie Byrd Land.

From this mountain we could see 35 to 40 miles farther eastward. The mountains appeared to be progressively lower. To the southeast of us the tabular mountains—the structural equivalents of Mount Fridtjof Nansen—were not more than 8,000 feet high. They define the southern boundary of the great glacier that flows down from the southeast. The whole fault structure seems to flatten out eastwards. The very large glaciers near the end of our trek coalesce to form a vast ice apron, which made travel both difficult and hazardous. The east-west-trending glacier in Marie Byrd Land pours forth such a volume of ice that it dominates the direction of flow along the whole mountain front with the result already noted in connection with Liv Glacier, namely that the flow of ice from the plateau instead of being directly northward as one might expect is toward the northwest.

Viewed as a whole the ice flow along the foot of the mountains gave the unmistakable impression that the ice is much less active now than formerly, probably when it was thicker. Most of the larger crevasses seem to have long been stagnant and to have become completely filled with snow and iced over. Throughout our journey from Axel Heiberg Glacier to Marie Byrd Land and return we heard no cracking as of ice under great strain and saw no unmistakable fresh crevasses. Ten miles beyond the mouth of one of the larger glaciers we found a great granite erratic (pl. 7, fig. 1), which seemed disproportionately large to have been carried so far by the present stream of ice.

On December 20 we left Marie Byrd Land and started westward toward our base camp. On Christmas Day we quite accidentally stumbled onto what we had formerly looked for in vain—the cairn left on Mount Betty by Amundsen 18 years earlier when he was northward bound for Framheim from the pole. The next day found us at Strom Camp making preparations for the return journey to Little America.

SUMMARY OF GEOGRAPHIC RELATIONSHIPS

In summary, certain geographic relationships stood out as we completed our work at the mountains:

The fault-block mountain structure of South Victoria Land is extended more than 300 miles farther across the continent than it had previously been known to exist.

Carmen Land of Amundsen, together of course with its possible connection with nonexistent lands between latitudes 81° and 82° , is removed from the map.

The Queen Maud Mountains proper do not trend southeastward from Axel Heiberg Glacier. This supposed plateau range represents but the peaks that fringe the great outlet glaciers. From far out on the shelf ice we could look many miles up these glaciers, and Thorne was able to get sights on peaks along the glaciers at great distances behind the front ranges themselves. It will be noticed that Beardmore Glacier is fringed by such mountains, and it is easy to see how anyone sledging or flying some distance to the east or west of such a glacier and parallel to it would get the definite impression that he was seeing a new mountain range. Yet it is at once apparent that all of these are integral parts of the geological structure of the great Queen Maud system itself.

Though the coal measures are not coextensive with the Beacon sandstone, yet they are sufficiently so to enable us to state rather definitely that the Antarctic has coal reserves second only to those of the United States. The discovery of coal on Mount Fridtjof Nansen and the extension of the Beacon sandstones at least to longitude 145° W. add many thousands of square miles to the coal areas already known in South Victoria Land.

The removal of Carmen Land from the map and the extension of the Ross Shelf Ice eastward at least as far as the one hundred and fortieth meridian in the latitude of our journey reopens the old question of the connection of Ross and Weddell Seas. Two newly observed features offer possible objections to this hypothesis—Leverett Glacier and the Edsel Ford Mountains. Leverett Glacier is by all odds the largest outlet glacier seen by us; and, so far as we could tell, the relatively small streams of ice that fed it from the south were insufficient to account for its great volume. Its very direction of flow suggests a source not necessarily from the south but rather from some great opening toward the east, as though there were a mountain wall in that direction. Nevertheless we could see no such structure, and it may possibly be explained by the existence of larger tributary glaciers from the south beyond our vision. The nunataks east of Supporting Party Mountain help to give it a westerly flow.

The Edsel Ford Mountains beyond King Edward VII Land, discovered on the flight of December 5, 1929, were photographed from so great a distance that one can not draw positive conclusions from the aerial photographs. But these appear to show a great range with a straight fault-line scarp that suggests the structure of the Queen Maud Mountains. It is possible that these new mountains are connected somewhere with the Queen Maud Mountains and so constitute the eastern structural boundary of the great Ross *senkungsfeld*. This of course does not necessarily follow. At any rate, what is one

of the greatest questions in the geologic relationship of major structures anywhere in the world remains still to be answered—the relationship of East to West Antarctica. Investigation of the Edsel Ford Mountains would probably add important and perhaps definitive light on this question. These mountains may be not the fault-block type but a folded Andean structure, for it is in this part of the Antarctic that one would expect a continuation of the fold structures of the Antarctic Archipelago if they reappear anywhere.

THE ROSS SHELF ICE

Because of the fact that the journey of the geological party threw much light on it, I have left until the end any discussion of the most distinctive of Antarctic glacial features, the Ross Shelf Ice.

From the time of its discovery by Sir James Clark Ross in 1840 to this day the Ross Shelf Ice, to employ a term that seems preferable to Ross Barrier, has impressed Antarctic explorers as one of the unique works of nature. It ends on the north in a dazzlingly white cliff that stretches for 500 miles in an east-west direction roughly in latitude 78° S. It is thus the boundary of the southern navigable limits of the Ross Sea. This great snow-ice cliff prevented Ross from sailing farther south in his quest for the magnetic pole and hence was referred to by him as a barrier. If the term Ross Barrier is to be used at all it should refer only to the northward-facing cliff of this great sheet of shelf ice that covers well over a quarter of a million square miles.

This cliff, or barrier, varies greatly in height from place to place and from time to time. It was restudied, for the first time after its discovery, by Scott in 1901–1904. He made soundings all along its front and also measured its height above sea level. The soundings demonstrated that the water was everywhere too deep for any part of the front of the shelf ice to be resting on the bottom. He found the altitude to vary from 20 to 240 feet above sea level. The next observations were those made by the British Antarctic expedition in 1907–1909 and indicated a height ranging from 20 to 200 feet. When the *Terra Nova* visited the region in 1911 no spot higher than 150 feet was observed. We of the Byrd expedition made our first landing at Discovery Inlet. Here we found the height to be 60 feet. From here we sailed eastward along the shelf-ice scarp to the Bay of Whales; and, though we did not land again to make accurate measurements, there was no place along this stretch that seemed higher than at Discovery Inlet. In places it descended as low as from 6 to 10 feet. Immediately east of the Bay of Whales, in fact bounding a part of it, the height was found by measurement to be 200 feet.

ORIGIN OF THE ROSS SHELF ICE

Scott believed the present shelf ice to be a relict or direct descendant of the old and much greater structure formed during the period of maximum glaciation. David elaborated this idea. He described the shelf ice as being essentially a great shrunken piedmont formed mainly by the confluence of the glacial streams that flow down from the plateau and fan out.⁵ These great ice streams are, in other words, ribs that flatten out away from their sources. The intervals between them have been frozen over, and snow has accumulated upon this sea ice until the whole has assumed a more or less common level.

Priestley differentiates two main methods of shelf-ice formation according to the relative importance of the basal element, whether sea ice or land ice. He believes that the Ross Shelf Ice originated chiefly upon sea ice formed in a comparatively landlocked and shoal area.⁶

It is quite impossible to estimate quantitatively the relative importance of these two sources of supply, land ice and sea ice, for the ice shelf. Unquestionably the great outlet glaciers such as Beardmore, Liv, and the rest are more important sources and are the causes of the movements within the shelf ice itself. Yet when we crossed the shelf at its widest part on our way to and from the Queen Maud Mountains we failed to observe any undulations that might represent the ribs, and we did get the very distinct impression that the greater part might have been formed essentially by sea ice becoming permanent and snow accumulating upon it. In the vicinity of the Bay of Whales we saw no evidence that glacial ice ever played a part. Not even in the overturned icebergs did we find any unmistakable glacial ice. Little America was built upon a shelf-ice bay 30 feet above sea level surrounded on the inland sides by older and higher shelf ice. According to Martin Ronne, who was with Amundsen, the Little America basin was a bay of open water with an iceberg in it back in 1911-12 when Amundsen was established near by at Franheim. The independence of this newer piece of shelf ice is evidenced by the fact that where it merges with the older and higher shelf ice it is yet separated from it by planes of disjunction indicated either by crevasses or definitely aligned haycocks.

CHANGES IN THE SHELF FRONT

Scott's earliest observations showed that in places masses of ice as much as 35 to 40 miles in width had gone out to sea since it was first charted by Ross. The whole ice front at that time appeared to have retreated some 30 miles since Ross's visit. Neverthe-

⁵ David, T. W. E., and Priestley, R. E., *Geology* (Sci. Results British Antarctic Expedition 1907-1909), vol. 1, p. 125, London, 1914.

⁶ Wright, C. S., and Priestley, R. E., *Glaciology* (British (*Terra Nova*) Antarctic Expedition 1910-1913), pp. 163-169 and 205-222, London, 1922.

less, since the first surveys by Scott in 1902 the shelf-ice front or barrier does not seem to have appreciably changed its latitude; yet there have been great northward movements in parts of it. Alternate observations by Scott and Shackleton near McMurdo Sound indicate a northward movement of more than 1,000 feet a year; but even here the front has remained more or less stationary. The ice is pushed forward, breaks off as bergs, and floats away. We have no measurements giving us a definite northward rate of movement anywhere else. Eastward from Discovery Inlet to the Bay of Whales our hasty observations indicated that there had been no fundamental changes in outline since the Scott survey of 1902. True enough, Discovery Inlet had a somewhat different outline from that given on Scott's charts: but it was still obviously the same bay mapped by Scott.

We found in places that the outline of the Bay of Whales had greatly changed since Amundsen's surveys. With the help of Ronne we were able rather definitely to locate Framheim, and so far as we can judge from Amundsen's astronomical observations compared with our own there has been no pronounced northward movement since his time. Cape Man's Head, one of the most distinctive features on the east side of the bay, looks very much as it did when photographed by Amundsen. Nevertheless, there is a considerable amount of movement in the shelf ice about the Bay of Whales; and the ice of the bay itself underwent profound changes even during our brief stay beside it. From the southern end of the Bay of Whales we noted the same two great zones of active crevasses observed by Amundsen. One trends southwest and the other southeast, and both could be followed inland 30 to 40 miles. The ice of the Bay of Whales itself is subject to intense lateral thrusts. In places the strain has been relieved by the formation of the great pressure ridges; in other parts of the bay and often between the pressure ridges themselves the ice has been squeezed into a great series of veritable anticlines and synclines. In the main part of the bay the axes of these folds are parallel to the axis of the bay. Whence come the great thrusts that have caused all this disturbance without noticeably affecting the shelf-ice boundaries on either side is still largely a mystery. A complete aerial survey was made of the bay, and perhaps when the mosaic is completed we shall be able to answer this question and further determine the relation of the major crevasse zones to the ice phenomena of the bay itself.

In attempting to reach Little America during the summer of 1930 the *City of New York* was blown far to the westward, fetching up against the shelf ice within sight of Mount Erebus; and thus in order to reach the Bay of Whales she had to sail along almost its entire front. Time was too short to make any but the most hasty

surveys. These did not include accurate latitude measurements of the shelf-ice front to see whether it had advanced or receded. They did, however, show many changes in outline along the portion westward from Discovery Inlet. Where Scott had found indentations there were now none, and again new indentations had formed where there were none before.

It is of interest here to return to the observations made by the geological party. The very direction of the ice flow along the foot of the mountains mapped indicates a maximum outward push in the western portion of the shelf ice, to say nothing, of course, of the great amount of ice flowing out from Beardmore and the other outlet glaciers west of Liv. Furthermore, the crevasses between latitudes 81° and 82° indicate that the shelf ice is here held back by land or a submerged reef of some sort which definitely obstructs the direct northward flow of ice. Again, the great hill south of Little America further blocks a northward movement of the shelf ice; and finally Commander Byrd found crevasses in latitude $80^{\circ} 45'$ S., longitude 173° W., west of the crevassed region we crossed. These observations but further substantiate David's studies that from Discovery Inlet eastward the shelf-ice front has not undergone great changes in recent years.

COMPOSITION OF THE SHELF ICE

The presence of numerous crevasses about Little America as well as the exposed face of the shelf ice gave us abundant opportunity to study its composition. Everywhere above sea level it is made up of snow. The top few inches to 3 or 4 feet is made up of ordinary snow. The remainder down to sea level is composed of granular snow. Nowhere could we make out a systematic arrangement of layers of this granular snow. Sufficient melting to form crusts is rare, and there seems little or no way to distinguish between seasonal amounts of precipitation. The speed with which this granular snow accommodates itself by flowage was a surprise to all of us. Haines and Harrison, the meteorologists, made a snow house for storing their kites; and at a depth of about 5 feet below the surface level they dug caves horizontally into the walls to make additional storage room. Within four months the roofs of these small caves had sagged as much as 6 to 8 inches across a span of 4 feet. All this happened under the severest temperature conditions of the year. The caves were made in the late fall, and the measurements were taken in the spring.

Particularly where the crevasses go down to the sea the rising moist air has left along the walls and pendant from the roofs an array of ice crystals prodigious in size and infinitely varied in form while always of the hexagonal system. It was common to find individual crystals from 5 to 10 inches across.



Photograph by A. C. McKinley

1. AERIAL VIEW OF THE MAIN GROUP OF THE ROCKEFELLER MOUNTAINS



2. TYPICAL VIEW IN THE ROCKEFELLER MOUNTAINS



Photograph by A. C. McKinley

1. OUTLET OF LIV GLACIER, SHOWING SYSTEM OF CREVASSES

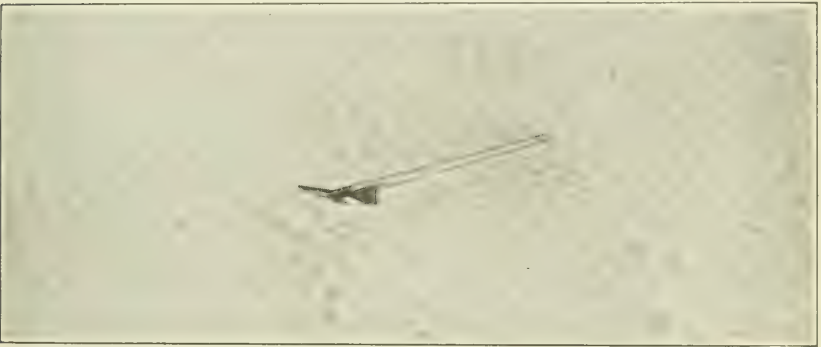


Photograph by A. C. McKinley

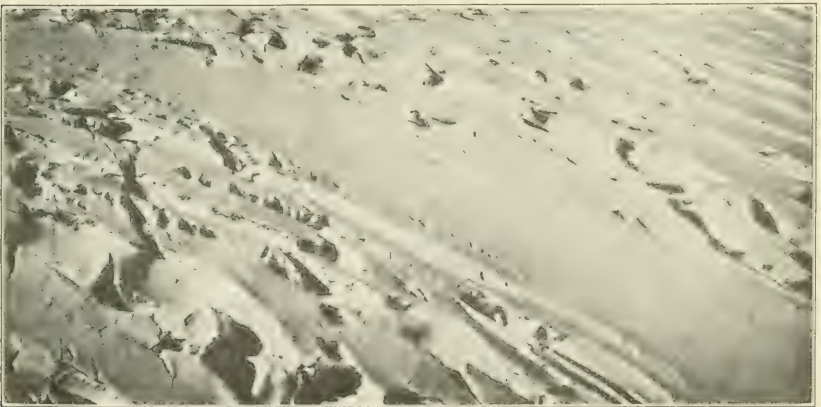
2. MOUNT FRIDTJOF NANSEN, IN THE BACKGROUND



1. "SASTRUGI" ON THE SHELF-ICE SURFACE NEAR THE MOUNTAINS
The ski stick gives a scale.

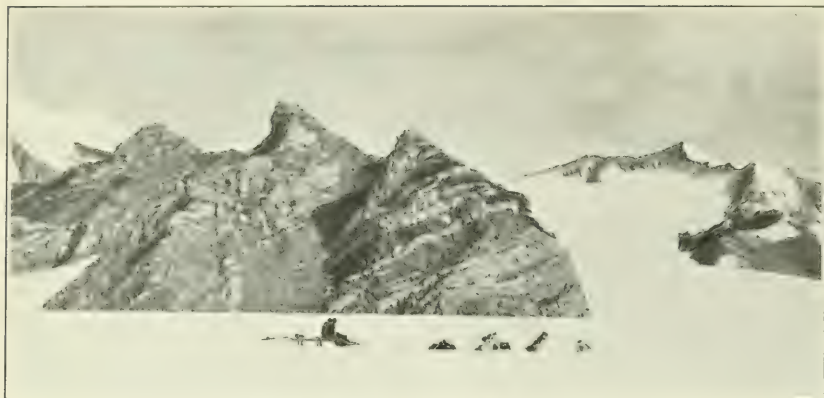


2. HARD-PEBBLED OR RIPPLE-MARKED SNOW SURFACE NEAR THE MOUNTAINS



Photograph by A. C. McKinley

3. CREVASSES IN LIV GLACIER



1. ROCK FACE BETWEEN LIV AND AXEL HEIBERG GLACIERS



2. GLACIATED TOP IN LONGITUDE 157° W.



3. GLACIATED MOUNTAINS IN THE FRONT RANGES OF THE QUEEN MAUD MOUNTAINS IN LONGITUDE 157° W.



1. AXEL HEIBERG GLACIER WITH MOUNT FRIDTJOF NANSEN ON THE RIGHT, RUTH GADE ON THE LEFT, AND DON PEDRO CHRISTOPHERSON IN THE MIDDLE



2. LOW-LYING HILLS OF OLD PRE-CAMBRIAN ROCKS WITH HIGHER TABULAR MOUNTAINS IN BACKGROUND. LIV GLACIER AHEAD WITH MOUNT FRIDTJOF NANSEN ON THE LEFT



Photograph by A. C. McKinley

3. LIV GLACIER ON THE RIGHT, PRE-CAMBRIAN MOUNTAINS IN FOREGROUND WITH TABULAR MOUNTAINS CAPPED WITH BEACON SANDSTONE IN BACKGROUND



1. HORNS ON THE RIDGE SEPARATING THE HEAD OF LIV GLACIER FROM THE ONE NORTH OF MOUNT FRIDTJOF NANSEN



2. TOP OF MOUNT FRIDTJOF NANSEN, SHOWING BEACON SANDSTONE WITH DARK SILLS OF DOLERITE



3. FIRST BIG OUTLET GLACIER EAST OF AXEL HEIBERG



1. A GREAT GRANITE ERRATIC AT MOUTH OF THORNE GLACIER



2. MOUTH OF THORNE GLACIER



3. CAMP COMAN IN MARIE BYRD LAND. SHOWING DARK PRE-CAMBRIAN METAMORPHICS INTRUDED BY YOUNGER LIGHT-COLORED GRANITES AND PEGMATITES

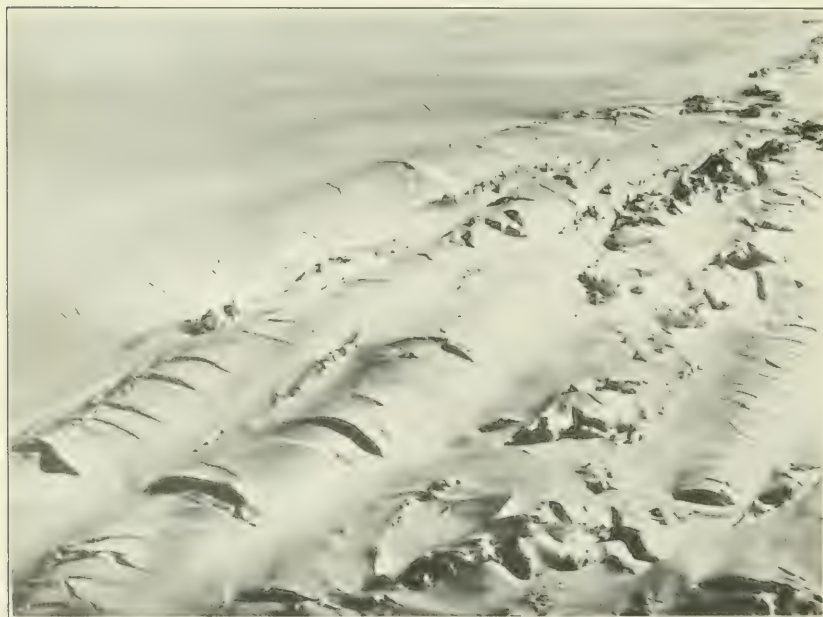


4. FRONT RANGES IN MARIE BYRD LAND



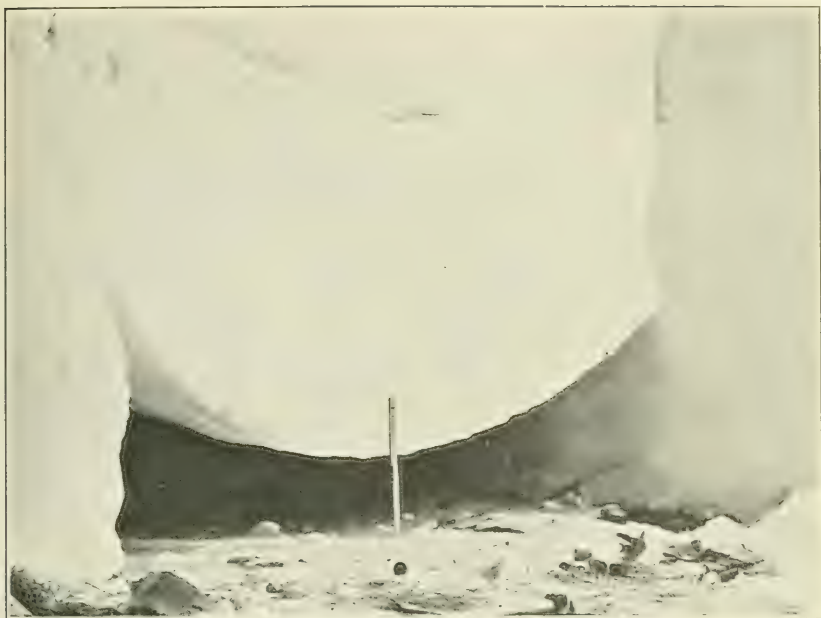
Photograph by A. C. McKinley

1. FAULTING AND FOLDING IN BAY OF WHALES



Photograph by A. C. McKinley

2. ROLL OR ANTICLINES IN BAY OF WHALES FORMED BY LATERAL PRESSURE



1. FLOWAGE OF THE SHELF ICE AS SEEN IN A SMALL STORAGE CAVE



2. ICE CRYSTAL

Crystals of this size are not uncommon.

SOME PHASES OF MODERN DEEP-SEA OCEANOGRAPHY

WITH A DESCRIPTION OF SOME OF THE EQUIPMENT AND METHODS OF THE
NEWLY FORMED WOODS HOLE OCEANOGRAPHIC INSTITUTION¹

By C. O'D. ISELIN, II

[With 4 plates]

Until recent years physical oceanography was too frequently considered a branch of science having little importance except to those interested in the ocean itself. This feeling perhaps resulted from the fact that on the earlier expeditions the main emphasis was placed on marine biology, and physical observations were first made mainly with the purpose of exploring the environment of marine plants and animals. Later there developed the necessity of studying the ocean currents and their influence in the transportation of sea life. As a result the physical oceanographer came to be thought of as one who charted the various physical characteristics of the ocean and who had as his ultimate goal the understanding of oceanic circulation.

At the present time, however, it is becoming increasingly evident that several other branches of science must turn to the sea, and therefore to the oceanographers, for help, for only in oceanography can be found the men and equipment for the investigation of the ocean and the problems related to it. Let us briefly consider some examples in which the oceanographer can do important work outside the original conception of his field.

In the first place, geology is naturally much concerned with the ocean basins. Have they been permanent features on the earth's surface, or in the past has there been dry land where now the chart shows one or more thousand fathoms of water? Convincing proof that will settle this problem one way or another can perhaps be brought to light by the oceanographer. A careful study of marine deposits might point to former land bridges between the continents in such a way that they could be accurately located and even dated, much to the satisfaction of all students of the geographic distribution of modern plants and animals, as well as to geologists. Perhaps a less spectacular problem is that of the formation of continental

¹ Contribution No. 14, of the Woods Hole Oceanographic Institution.

shelves. Again there is reason to believe that the question can best be settled by a careful study of bottom deposits. Thus oceanographic institutions, having developed a technique for bringing up deep-sea mud in the course of exploring the oceans, are now realizing more fully the wide geologic importance of this type of work. With proper equipment much can be learned from the ocean bottom which will extend geologic knowledge out beyond the beach line and perhaps open up a sounder theory for the formation of the earth's surface.

In the same way, but perhaps not to the same extent, meteorological investigations have been largely confined to the air above the continents. Not only is there much meteorological research work to be done at sea, but this science is closely bound up with oceanography. For example, how much influence have fluctuations in the ocean currents on variations in climate and vice versa? From a more technical standpoint, students in dynamic meteorology and dynamic oceanography now see more clearly how similar is the principle of the circulation of the atmosphere to that of the ocean. Thus we can expect in the future a closer relationship between the physical oceanographer and other geophysical students, for many of their problems are interrelated.

On the other hand, the scope and importance of marine biological work has been more generally recognized and in certain lines, for example, fisheries investigations, has developed relatively fast. The many marine laboratories of the world are good evidence that physiologists have realized the importance of studying life in its most natural environment. Hand in hand with the development of marine biology has gone the study of the chemistry of sea water and such questions as the penetration of light below the sea surface and its influence on the life in the upper water layers.

Thus at the present time, oceanography has passed the stage of a science in which the collection and tabulation of facts is considered the main aim, and it is now evident that much productive research of wide interest can be carried out at sea. The reader perhaps now realizes that an oceanographic institution must have on its staff men of wide training and experience in science as well as the specialists in the more restricted phases of oceanography.

The investigation of the ocean naturally divides itself into deep-water problems and shallow-water problems. The well-known fact that most continental land masses are surrounded by a broad, relatively shallow shelf of water less than 100 fathoms deep and that the ocean basins are uniformly twenty or thirty times as deep, serves to emphasize this distinction. Investigations along the coast and even out as far as the edge of the continental shelf can be

carried out from almost any boat and with quite inexpensive equipment. Deep-sea oceanography, on the other hand, is an expensive undertaking requiring a strong, able vessel and elaborate winches and instruments. For these reasons there are a number of scientific institutions actively engaged in studies of the shallow-water areas of the ocean, but relatively few can conduct researches outside the hundred-fathom curve. In several ways this state of affairs has been unfortunate in the development of some phases of oceanography, because the shallow waters over the continental shelves are usually much affected by the circulation of the waters of the ocean basins, while tidal and other influences often obscure the picture to such an extent that isolated problems can not be easily settled.

On the other hand, the shallow-water areas are, of course, the seat of the world's fisheries and for that reason merit governmental study. But even in the case of fisheries investigations, the oceanic waters can not be ignored, because it has been shown that the sudden failures of a fishing ground are sometimes caused by movements of the oceanic waters which periodically flood in over the banks, changing the temperature of the bottom water and driving off the fish. In other words, the investigation of the sea has progressed largely from the shore outward, while it is now evident that there would have been some advantage to oceanography as a whole if it had been possible to put more effort into deep-sea investigations during the early stages of the science. It is perhaps not an exaggeration to say that the heart of most oceanographic problems is to be found in the deep ocean beyond the limits of the continental shelves.

The fact that there has recently been established in the United States an institution largely devoted to deep-sea oceanography is therefore of considerable interest. The Woods Hole Oceanographic Institution, with its headquarters on Cape Cod, is ideally situated for the investigation of the North Atlantic Ocean. The institution is now a going concern with adequate money to support a well-equipped laboratory at Woods Hole, Mass., and a specially designed research ship. If, in the succeeding pages, the reader finds that we have stressed the equipment and methods of this institution unduly, it is because it was founded to counteract the situation in oceanography outlined above and in many ways, we believe, holds a unique position in the world to-day.

The main distinction between an oceanographer and other men of science is that the oceanographer goes to sea. His ship is the all-important part of his scientific equipment for he must be able to make observations in all kinds of weather and at great depths. Not only must he often remain far out at sea for months at a time, but also he must be ready to take an active part in securing his observations.

No matter how well trained the research ship's crew may be, the scientist must thoroughly understand the difficulties and limitations of the work, or he will not be able to evaluate the results properly or suggest practical programs for scientific cruises.

Many types of vessels can be used for oceanography with good results. Fishing craft of various types have proved very satisfactory. The main points are that the vessel should be entirely seaworthy and able to remain at sea longer than ordinary commercial usage requires. For the investigator of the chemistry of sea water especially, the steadier the ship, the more accurate will be his work. But to gain steadiness by using a large ship is often a disadvantage. If the boat is too large, besides being expensive to operate, the scientists are not close enough to the water to handle easily much of their equipment. One solution is to use a sailing vessel, because the sails tend to prevent the boat from rolling excessively in a rough sea. In oceanography, then, we find one instance, at least, where the sailing ship can hold out successfully against the inroads of steam.

One of the most modern examples of a scientific research ship is the *Atlantis* operated by the Woods Hole Oceanographic Institution. She was built especially for the work, after considerable thought, and embodies the experience of many men familiar with carrying out scientific work at sea. The result is a boat that is very satisfactory and at least represents one solution to the problem. She is an auxiliary, steel ketch of about 460 tons displacement, and carries 7,200 square feet of canvas. Her general dimensions are: Length on deck, 142 feet; beam, 29 feet; and draft, 17 feet. She is powered with a 280-horsepower Diesel engine, which besides propelling the ship at a speed of 9 knots in calm weather, supplies through a dynamo the power for the heavy trawl winch. A much smaller Diesel engine generates the power for light, ventilation, and refrigeration, as well as for the hydrographic winch. Perhaps the most specialized piece of equipment is the trawl winch, located, because of its great weight, in the lower hold. It carries 5,000 fathoms of special steel cable of $\frac{1}{2}$ -inch diameter, with a breaking strain of about 12 tons. The hydrographic winch, used mainly for lighter work such as securing deep-sea temperatures and water samples, carries a similar length of much lighter wire and is located on deck. Both winches are electrically driven and fitted with automatic devices for guiding the wire smoothly on the drums.

The *Atlantis* accommodations include cabins aft for a scientific staff of five, and amidships two laboratories, one opening out to the deck where the rough work is done and another directly below it where the chemical analyses are carried out and where the microbiologist can examine the catch of his silk net without being dis-

turbed. The permanent crew, exclusive of the scientific staff, numbers 17 men. They have comfortable quarters, and there is ample storage space below decks. The vessel is a smart sailer and an excellent sea boat. Her rig, though small for the size of the hull, is efficient and ideally adapted for heaving to, which is most important for this type of work.

The primary instrument of the physical oceanographer is the deep-sea reversing thermometer. These are now sent down in pairs, one open to the pressure of the water and the other inclosed in a heavy glass case. The significance of this we will see presently. Both the protected and the unprotected thermometers are of the same construction. On being turned over the column of mercury breaks off at a constriction in the capillary and the temperature is read as the length of this detached thread of mercury. Thus the reading can not be changed on the long haul to the surface by passing through the much warmer surface layers. The deep-sea thermometers are now very accurate and can record the temperature to a hundredth part of a degree centigrade. The pairs of thermometers are sent down in frames which are mounted on the side of instruments known as water bottles. These are fastened to the wire cable at suitable intervals and lowered over the ship's side. A small weight, or messenger, is then slid down the wire, which, on striking the uppermost instrument, closes the openings of the water bottle, reverses the thermometers, and releases another messenger which slides on down the wire and repeats the operation with the next instrument. Thus a series of 10 or more water samples and pairs of thermometer readings can be secured at one lowering. In deep water it may take several such lowerings, each successively deeper, to constitute a station.

Although the thermometers and water bottles have been in use for many years and have gradually become much improved in design, there was still one grave inaccuracy which has only recently been eliminated. The depth of each observation was formerly recorded as the length of wire, measured on a wheel of known circumference, from the sea surface to each water bottle. However, in general the wire did not remain vertical in the water. The angle the wire took depended on the relative motions of the ship, the surface layers, and the deep, nearly motionless water masses. In other words, the wire would not only enter the water at an angle, but probably formed an S-shaped curve of unknown extent, so that the depths of all observations was problematical. Since one of the purposes of temperature and salinity observations is to assist in the study of ocean currents—and in regions of currents the trouble of large wire angles (often as much as 40° from the vertical) is at a maximum—it

was a great advance when the use of unprotected thermometers became general a few years ago. This method really measures the pressure existing at each instrument of a given series and from these the depths are calculated. The pressure of the water compresses the glass of the unprotected thermometer and makes it read higher than the protected thermometer with which it is paired. The difference in reading between the two instruments can then be translated into depth and with a surprising degree of accuracy. Not only are reliable depths now secured for the temperature observations taken from a modern research ship, but of course these same depths are good for the samples brought up by the water bottles. The water samples are of sufficient volume so that besides salinity, several other chemical factors can be determined. In fact, all physical observations made with this apparatus are now on a comparatively accurate basis.

The primary collecting instrument of the marine biologist is, of course, a net of one sort or another. Many different types are employed, depending on what type of animals or plants are sought and on whether the collections are to be obtained from the bottom, the surface, or intermediate depths. Of late years, attention (formerly directed chiefly to the bottom fauna) has been largely centered on the drifting community of animals and plants—the so-called “plankton”—which are captured as a rule with some form of tow net. Tows made deep down in the water have, until recently, been confused by the same inaccuracy as have the routine physical observations, namely, the uncertainty as to the precise depths from which the captured specimens came. Not only was the maximum depth reached by the net uncertain but also the animals might have gotten in on the way down or on the way up. This last source of error is especially serious in the case of deep-sea tows, for with these the time involved in lowering and raising the net may be several times as long as the horizontal tow itself. Even for plankton work near the surface, it has been difficult to know at just what depth the net had been fishing or to do accurate quantitative work with more than one net at a time. Improvement in the technique of tow-net work has come gradually and is perhaps not yet at a satisfactory stage of development.

One of the first steps was the perfecting of nets which can be sent down closed, opened during the tow, and closed again before being hauled to the surface. Another improvement has been the use of a kind of bucket at the back end of the net which protects the catch from being rubbed too much against the netting during the long haul to the surface. As many deep-sea animals are ruined as specimens through this cause as through the release in pressure

on nearing the surface. This destructive release in pressure, which at first destroyed nearly all specimens of deep-sea fish by causing gas bubbles to form in the tissue, can now be fairly well prevented by using much the same methods as employed in raising a diver.

Recently on the *Atlantis* it has been found possible to make as many as five simultaneous tows with closing nets and know the exact depth of each catch. In this method the wire is so heavily weighted that it remains practically vertical during the tow and the nets are fastened to it one below the other at known intervals. A system of messengers sent down the wire operate the opening and closing devices of the nets. Not only are the opening and closing devices extremely satisfactory but also a further refinement has resulted. Since the frames of the nets are fastened to the wire rigidly, there is no bridle in front of the opening to scare away the animals in the net's path. With large deep-sea nets designed for catching more active animals such refinements are not yet in practice. In fact, even though the net used may be of the closing type, the depth at which the catch is made usually becomes somewhat problematical if the towing wire is at any considerable angle from the vertical. There has been some experiment with pressure instruments which should record the depth of the net at all times during the tow, but there are still many difficulties which must be met. The technique of deep-sea tow-net work is further complicated by the fact that the nets used to-day do not stand much hard usage and soon develop holes and tears which always try the patience of the oceanographer. It is a matter of time and money before biological work at sea can be conducted with satisfactory accuracy.

The study of bottom samples taken from the floor of the ocean has always been productive and has aroused considerable interest among geologists as well as oceanographers. The recent developments in this field have also much improved the accuracy and use of the observations. The old-fashioned piano-wire sounding machine can now be replaced by the accurate and almost automatic sonic method, so that the exact depth of the water can be found at all times. Formerly it took several hours to make each sounding and by the time the wire was hauled back aboard, the vessel could have drifted into water having a different depth. For all bottom sample work, the operation is made much easier by knowing the depth in advance. Otherwise several hundred fathoms extra wire may be run out before the observer is sure his sampling device has reached bottom. With any sampler more complicated than the ordinary sounding tube this may be a great disadvantage. The extra cable coiled on the bottom may kink and the instrument will probably be lost when strain is again put on the wire.

It is a great advantage to investigators to have the bottom sample come up in a water-tight condition so that none of the fine washings are lost on the long haul to the surface. To meet these requirements much attention has been devoted, of late, to devising improvements on the simple "snapper" and other devices which have long been used. For example, various types of valves have been tried that will prevent the mud from washing out of the sounding tube. Other more modern samplers are designed to secure long cores of the bottom material. With the present equipment, samples up to 3 or 4 feet in length have been brought up, and these have shown that the deposits on the ocean floor are often stratified. It is through the study of such material that eventually the problem of whether or not the bottom of the present deep ocean has ever been above sea-level will probably be settled. Still another type of sampler has been gradually evolved that will take either sand or mud from the region over the continental shelf. Another type, mainly used in shallow water, brings up a given area of the bottom which can then be studied for the plant and animal life and their relations as a feeding ground of commercial fish.

We have perhaps described enough of the modern oceanographic equipment to show the reader that not only is the design of all gear being gradually improved, but that the technique of securing good observations from a small ship can not be easy even in favorable weather. It is this mechanical or engineering side of oceanography that has attracted a good many men to the field. It often seems to the harassed investigator that the sea hides some monster which is most antagonistic to having his realm explored. Unforeseen things are constantly hampering the work of each oceanographic expedition. For example, there are several kinds of marine animals which become wound around the hydrographic wire and stop the messengers. Often a piece of apparatus comes up which has not worked because the messenger never reached it, and this after hours of waiting while miles of cable were unwound and rewound on the winch. If the submarine "devils" are not interfering with the work, the "devils" of stormy weather are very apt to seize the opportunity to persecute the sleepy oceanographer who has perhaps been struggling for hours to complete a series of observations. In wintertime it is a real fight to go to sea and to return home with any of the secrets of the sea safely recorded in the scientific log book. Thus storms and salt water must be combated continually; and although most sensible people very wisely stay ashore, the work at sea holds a real fascination through its difficulties and discomforts, to a small but enthusiastic group of men working in the various oceanographic fields.

In order that those unfamiliar with deep-sea oceanographic work may get some idea of the type of problems now being studied, we will describe presently the investigations made by the *Atlantis* during the past year. Since these have been largely in the field of physical oceanography it will be necessary first to point out a few of the features of the circulation of the North Atlantic, bearing in mind that, although we will be discussing the North Atlantic, the same problems exist in the other oceans, as they all work in the same manner. Therefore, discoveries in any ocean can usually be applied to the others. In other words, it is not necessary to sail very great distances to do important oceanographic research.

The current system of the North Atlantic basin, as in the case of the other oceans, is partly convectional in nature and partly wind-driven. Since the water is heated near the equator and cooled in the north, a current system is naturally set up owing to the distribution of density resulting from the thermal inequalities. On the other hand, the evaporation at the sea surface is probably on the whole greater than the precipitation in the southern half of the ocean, and the reverse in the north. Through this cause, the surface water is made relatively heavy in the south and thus the distribution of density due to temperature is partly counteracted and the convectional circulation, much dependent on temperature, somewhat retarded. It is thought that the Gulf Stream system is largely a manifestation of this need for thermal transfer from south to north.

In the southern North Atlantic the water movements are probably dominated by the trade winds which blow the surface waters westward towards the islands of the West Indies, so that the water level in the Caribbean Sea and the Gulf of Mexico may be somewhat higher than farther north. At any rate, the result is a swift current through the Straits of Florida and the beginning of the Gulf Stream, which carries some of the warm southern water northward to the Grand Banks and then eastward toward Europe. But the forces which maintain the eastward drift in the northern latitudes are probably only partly convectional in nature, for in these latitudes the prevailing westerly winds undoubtedly exert a strong influence. In this manner a huge clockwise eddy is maintained in the North Atlantic.

Owing to the fact that the waters of the ocean are usually arranged in stable layers, and that Archimedian forces tend to keep these layers horizontal, unless disturbed by some outside force, the character of such a current as the Gulf Stream is surprising. Through the effect of the earth's rotation the normally horizontal water layers are sloped across the path of any current so that the lighter water

lies deeper on the right side (in the northern hemisphere). In the case of the Gulf Stream, this means that the warm water must lie deeper on the southeastern side. In other words, half of the current consists of relatively cold water and half of relatively warm water, because the isotherms slope sharply across its path. In the case of the 10° isotherm, for example, this means a slope of from 200 meters on the western side of the stream to 800 meters on the offshore edge, the current being about 50 miles wide off New York. The Gulf Stream then is not a river of warm water flowing through colder seas, but the boundary between a body of relatively cold water and the mass of warm, central, Atlantic water. It follows then that the Gulf Stream, by which we mean the whole of the convectional current along the eastern North American seaboard and not just the surface layer, does not transport the warmest water northeastward. Even at the surface, the warmest water is not over the stream unless displaced by easterly winds. From a technical point of view, it is wrong to think of the Gulf Stream as being a river of warm water, although it is the existence of warm water in the southern North Atlantic which is its cause. The current, because of the earth's rotation and the stable arrangement of the water layers, only accomplishes what it sets out to do in a most inefficient manner.

But besides this horizontal circulation, at the same time there exists much slower vertical movements. Some of the cold, relatively heavy northern water sinks and gradually moves southward along the bottom, only to rise again near the equator. That these two systems exist can be clearly and easily demonstrated from the observations already recorded, and some progress has been made by studying the pressure field of the ocean in much the same way as is done in meteorology. The region south and east of Bermuda, known as the Sargasso Sea, corresponds to a permanent high-pressure area on a weather map. Such southward-moving tongues of cold water as the Labrador current can be compared to the polar fronts of the meteorologists. But sea water, in contrast to air, is nearly incompressible and is usually found to be well stratified and therefore quite stable. Moreover, it is out of the question for oceanographers to secure any such instantaneous picture of the pressure field as in a weather map and besides it is not known to what extent the ocean circulation is wind driven.

Thus it is an unfortunate fact that as we look more closely into the ocean currents and attempt to find reasons for their paths and characteristics, we must admit that this phase of oceanography is at a most awkward stage. The existing observations are too few to explain more than the broadest picture, and as each expedition brings back modern data, that is, sections made up of closely spaced

stations, it is evident that many of the early ideas are unsound. Since it would be impracticable for any one institution to attempt a complete survey of the North Atlantic, all existing observations must be combined to show the general scheme of circulation and test cases must be studied to explain the peculiarities.

At the present time, among the foremost problems in ocean circulation are the following: (1) The relative importance of wind and convectional forces; (2) the question of whether ocean currents flow steadily and in continuous paths or spasmodically; (3) the effect of seasonal changes in surface temperature. As an initial approach to the first problem there is a need for quantitative data. What force does a wind exert at the sea surface? The question has been studied by the mathematician, Ekman, and the theory of his famous spiral is well known. It has been suggested that if the wind drives the surface layers of the ocean they in turn must retard the lower strata of air. Ekman's spiral should exist in both the ocean current set-up and in a reversed direction in the lower layers of the atmosphere. Since it is more easily measured from the meteorological point of view through pilot-balloon observations than in the ocean, it may be possible for students of aerodynamics to secure for oceanographers actual values of the force exerted at the sea surface by the wind.

The second problem, concerning the steadiness of ocean currents, is perhaps too technical to discuss here since it involves the usefulness of Bjerknes's equations. His theory for calculating the velocity of currents by the slope of the surfaces of equal density demands that the circulation has assumed a steady character. There is some reason to believe that ocean currents are usually either slowing up or increasing their velocity and often break down altogether. The immediate question before physical oceanographers is how far it is advisable to use for dynamic calculations stations from different expeditions or even from the same expedition, but made over a period of a month or more. It may be that in certain regions the ocean circulation is disturbed by eddies corresponding to the extra-tropical cyclones of meteorology, in which case nothing but simultaneous stations will give a true picture of the circulation. In the case of the northern areas of the Atlantic, the third problem is immediately brought up. Are the seasonal temperature changes in the surface layers powerful enough to alter the underlying dynamic forces?

There are many more perplexing questions having to do with circulation which are still unsettled, but the above is perhaps sufficient to show that the understanding of oceanic circulation is still in a very elementary stage in spite of what one might think from examining the very considerable literature on the subject, unfortunately mainly based on insufficient data. In other words, the

great need at present is for observations especially planned to bring out particular points rather than for stations scattered over wide areas. The crying need is for proof.

Now it may seem to the reader that oceanic circulation is a relatively unimportant scientific problem. It is true that for the purposes of navigation we now have sufficient knowledge of the main currents and that for such services as the ice patrol the existing methods give good results as applied to small areas. The reason why we have here stressed circulation is that almost every problem in deep-sea oceanography is somehow linked to it. The marine biologist can not adequately account for the distribution of life in the sea without a good knowledge of the water movements. The quantity of life in the sea is also linked to the current system since it depends on the supply of certain chemicals in the water. These essential chemicals are found in greatest abundance near the shore because they are brought to the sea by the rivers. When in a given area they are used up more quickly than the currents can carry them out from the shore, the population will die out. The sea is the original home of life as we know it on earth. For countless ages the evolution of marine forms must have been greatly influenced by the supply of these vital chemicals. If it were not for the circulation of the oceans, no matter how slow, large areas of it would be completely barren. The important part which the ocean currents are now playing (and have played in the past) in the climate of the world is more generally appreciated.

Anyone who has had experience in research work knows only too well how one thing leads to another. An investigator no sooner gets started on a problem than he finds that he can not progress until he has settled another problem, which only develops after he has begun work on the first. In oceanography the difficulty is increased by the fact that such vast distances have to be covered and it is usually impossible to repeat the work. It almost seems that it requires the experience of a preliminary cruise to know how to attack any given problem. For this reason anyone planning a program for scientific work at sea would do well not to attempt too much on one cruise. There is little hope of finding an important problem that can be settled by one expedition. Often it is the development of a technique for handling new apparatus which is the main result of an elaborately planned cruise. There is a vast supply of oceanographic problems, but little is known about methods for settling them.

With the formation of the Woods Hole Oceanographic Institution and the building of the *Atlantis* those interested realized only too well the difficulties of laying out a program. No longer was it a question of planning for an isolated expedition which must yield

a maximum of results in a given length of time. Rather, some policy had to be adopted which would tie together the very scattered information already in existence and at the same time prepare for future work that was bound to progress slowly.

The accompanying diagram shows the sections run by the *Atlantis* during the first 10 months of her existence. These sections

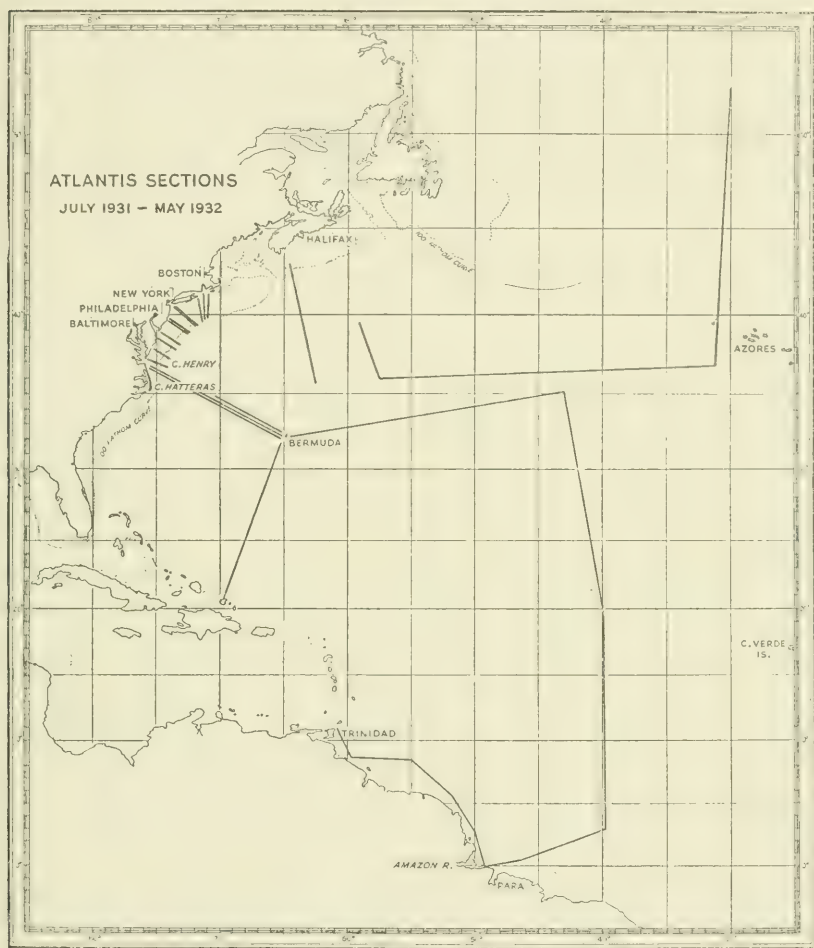


FIGURE 1.—*Atlantis* sections, July, 1931–May, 1932

consist of about 250 stations along lines totaling almost 10,700 miles in length. About two-thirds of the stations lie in deep water. Observations have been made always to 3,000 meters, when the depths of the water allowed, and at frequent intervals to the bottom.

The physical program of the institution centers around the two sections out to Bermuda. It is hoped that it will be possible to

repeat these sections quarterly. They should provide information concerning fluctuations in velocity and in volume of the Gulf Stream. They should show whether or not its path varies with the season and from year to year. Since on these sections the stations have been spaced at from 15 to 25 mile intervals, they should give reliable data on the internal arrangement of the water layers in what is perhaps a purely convectional current. The cruise from Nova Scotia to Bermuda and back to Chesapeake Bay can usually be made in under two weeks, so that the sections come very close to satisfying the ideal of giving an instantaneous picture.

Although this work is perhaps mainly of interest because it will supply detailed information on the Gulf Stream, the greater part of the sections lie in the relatively motionless mass of the central North Atlantic water. In this region between the Gulf Stream and Bermuda the stations will be most helpful in the study of such questions as internal boundary waves, the mixing action of storm waves, and other questions important over the whole ocean rather than applying to currents. Between the Gulf Stream and the edge of the continental shelf there is also another interesting band of water which is relatively cold at all depths when compared to the water just to the south and eastward. Yet it is not at all certain that this strip of water, which can be thought of as keeping the Gulf Stream away from northern Atlantic coasts, has a northern origin.

Besides these Bermuda sections the *Atlantis* has run two long north and south profiles in mid-Atlantic. The more northerly line of stations follows longitude 30° W. and crosses the North Atlantic Drift, as the continuation of the Gulf Stream is sometimes called. Before this section was run (July, 1931) there was evidence that the Gulf Stream split into at least three branches after leaving the region of the Grand Banks and that the prevailing westerly winds in this part of the ocean played an important part in the easterly movement of the surface waters. The *Atlantis* section of closely spaced stations should furnish important data concerning the water movements in this part of the ocean and at the same time definitely establish the branching nature of the continuation of the Gulf Stream.

The southern of these two profiles (February, 1932) follows longitude 42° W. and extends from the horse latitudes to the Equator. It therefore crosses the northern equatorial, or trade-wind, current. In theory, this section should show up the nature of a pure wind current besides giving the volume and velocity of the westerly drift across the southern part of the North Atlantic. It was hoped that the arrangement of the water layers in this type of current would

be strikingly different from those of the convectional current, so that it would be possible to decide roughly in other profiles how much of the movement was due to wind and how much to convectional forces. A preliminary examination of the observations has indicated that this was perhaps too much to hope for, yet the section will be most important when the time comes to establish in detail the water movements of the North Atlantic.

In the course of running these important sections, opportunity was found for examining several more special regions. In the first place, a section was made off the Amazon River (March, 1932) showing the transition from oceanic conditions to those of fresh water. This section will be mainly of interest from the chemical point of view. In the second place, a good section from the West Indies out to Bermuda was made (April, 1932) to show up the nature of the Antilles current. This is the current which is supposed to carry southern water northward outside the islands and to join with the Gulf Stream near the Straits of Florida. Finally several short sections have been run across the coastal waters between Cape Cod and Cape Hatteras, on the eastern seaboard of the United States. This work was in connection with a study of the coastal conditions throughout the year begun by the United States Bureau of Fisheries.

So much for the routine temperature and salinity observations made in deep water during the first year of the Woods Hole Oceanographic Institution. It must be remembered that in the course of collecting this huge number of water samples, the opportunity was not lost to examine them for oxygen content, P_h , P_2O_5 , and PO_4 . Therefore, the work has a most important chemical aspect besides giving data for the study of ocean currents.

In the field of marine meteorology, the work carried out on board the *Atlantis* has been mainly on two problems. Considerable data have accumulated that are being used to show more accurately the relationship between the rate of evaporation at the sea surface and the wind velocity, as well as its dependence on the stability of the lower layer of the atmosphere. About 100 pilot-balloon ascents have been observed with a theodolite over a large area of the Atlantic with a view of finding the frictional force exerted by the wind on the ocean surface. As is usually the case with scientific work at sea, it has taken considerable time to develop a satisfactory technique in making these observations.

From the geologic standpoint, the *Atlantis* has only done a small amount of work during the past year. An investigation of the problem of the formation of the continental shelf off the Atlantic coast States has been in progress in the laboratory at Woods Hole. Most

of the bottom samples have been collected by the *Asterias*, a 40-foot power boat also operated by the institution. But during April, 1932, two lines of stations were run by the *Atlantis* off the New Jersey coast with samples taken every 2 miles from the beach to the 1,000-fathom curve. By studying the distribution of the various sized particles composing the mud, it is hoped that something will be learned about the depth of wave action and the geologic history of the formation of the continental shelf.

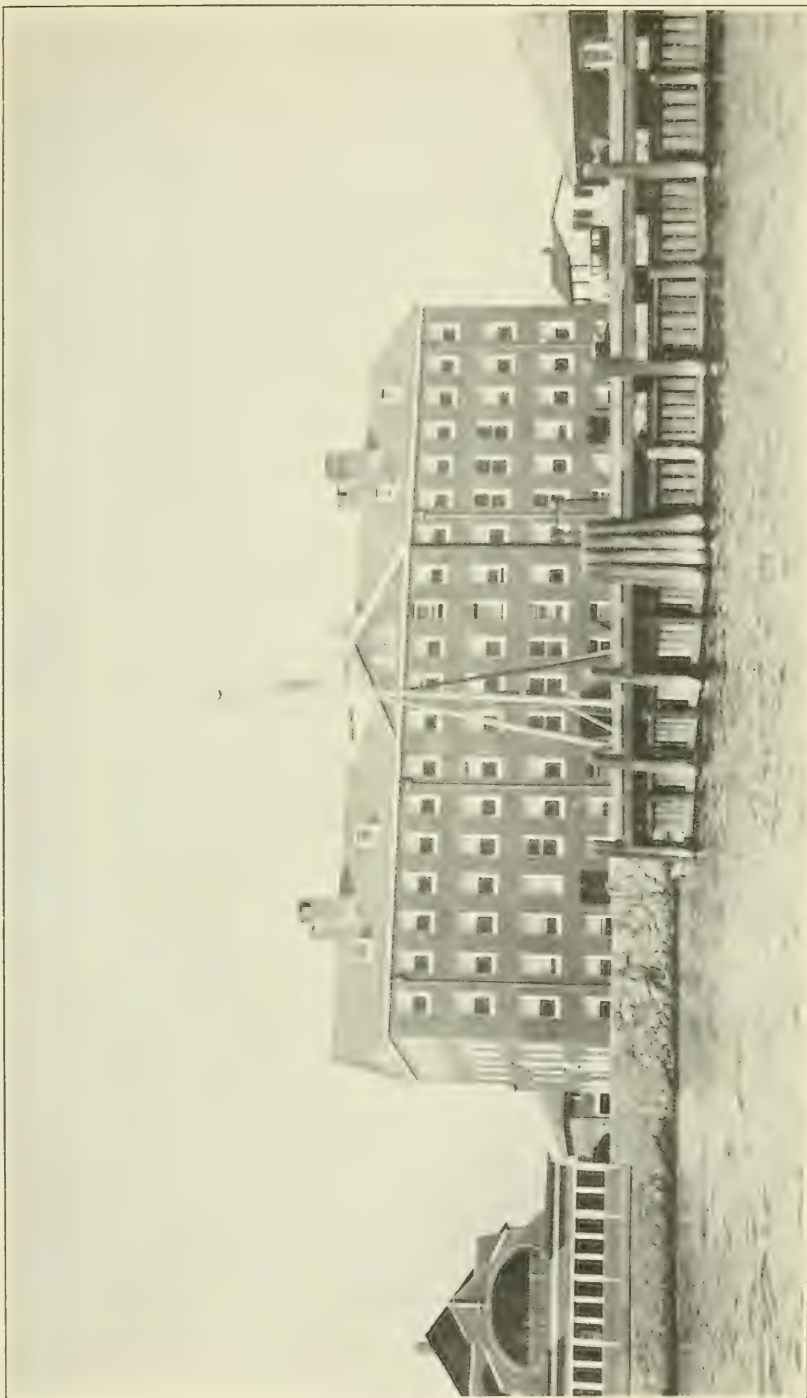
The physical program of the *Atlantis* has not been so extensive that some valuable biological investigations could not be carried out at the same time. During much of the year it has been the custom to make a tow for eel larvae every second evening when the vessel was cruising in suitable regions. These tows were made to collect eel larvae for the Carlsberg Laboratory in Copenhagen. Through a study of the distribution and sizes of the young eels, their migration route from the spawning region south and east of Bermuda has been mapped out, and since their long journey back to Europe is much dependent on the currents, the eel tows are valuable to physical oceanographers because the eels make excellent drift-bottles. At the same time, a general collection of oceanic plankton has been carried out for the laboratory at Bermuda, which will eventually show more clearly the distribution of the various small floating animals found near the surface in the central North Atlantic.

The *Atlantis's* heavy winch with its 5 miles of cable was intended mainly for handling large deep-sea nets and dredges. Her cruises to date have not included any program of bottom dredging, but enough deep-sea tows have been made to test the machinery thoroughly. These tows have advanced the technique of handling large nets, besides being instructive in the problem of bringing up deep-sea fish in good condition. There is even reason to expect that in regions where the surface waters are not too warm, deep-sea animals can be brought to the surface alive, if proper precautions are taken. The cod end of the nets must be lined with some soft material so that the fish will not have their skin chafed off by the rush of water through coarse netting and the hauling speeds must be so regulated that the animals have time to "decompress" on the way to the surface. The difficulty is that fish living normally in waters having a temperature of 4° C. will be killed by being brought through the surface layers which are usually very much warmer. It would seem that in winter, if tows were made in the northern seas, this difficulty might be eliminated and the fish brought back alive.

The question of the penetration of light below the sea surface and its effect on the animal life in the upper layers of the ocean has recently received considerable impetus through the development

of a reliable photometric apparatus at the Plymouth Laboratory. Similar apparatus was made for use on the *Atlantis* and during the summer of 1931 this was tried out on her crossing from Plymouth to Boston. At 13 stations careful measurements were made of the amount of light at all depths down to the limit imposed by the sensitivity of the photoelectric cells used. At the same time, through the use of a series of five closing nets, a picture of the vertical migration of the plankton was obtained which could be nicely correlated with the amount of light reaching the organisms throughout the day. Thus the phototropic effect can be studied at sea in much the same manner as in a physiological laboratory.

Such is a summary of the various investigations carried out from the *Atlantis* since her launching in June, 1931. This by no means represents all of the work of the Woods Hole Oceanographic Institution. A large number of marine problems have been attacked at the laboratory, and many observations have been collected by the *Asterias*, but it has been thought best to limit this account to the work done in deep water because so little is known of the problems of deep-sea oceanography.



LABORATORY AT WOODS HOLE



THE "ATLANTIS"

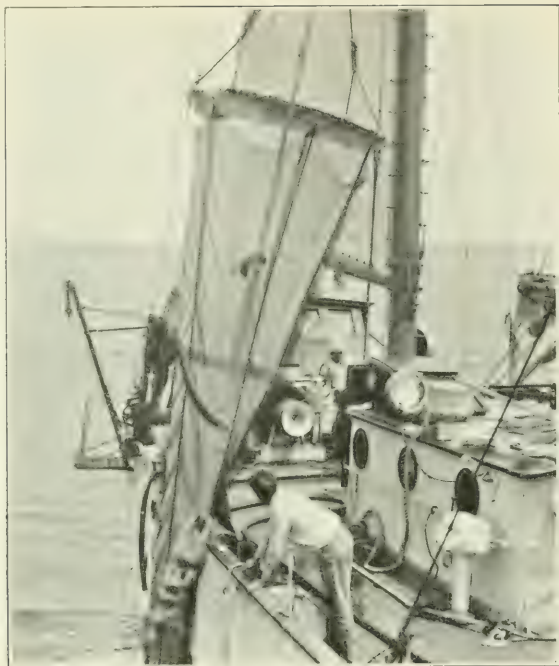
A scientific research ship operated by the Woods Hole Oceanographic Institution.



1. WATER BOTTLES BEING ATTACHED TO THE WIRE



2. WATER SAMPLES BEING DRAWN FROM THE WATER BOTTLES IN THE DECK LABORATORY ABOARD THE "ATLANTIS"



1. PLANKTON NET BEING HOISTED ABOARD AND
WASHED DOWN BY A HOSE



2. SHOWING CURRENT METER FASTENED IN THE MOUTH OF A NET TO
MEASURE THE VOLUME OF WATER PASSING THROUGH IT DURING A
TOW

SAFETY DEVICES IN WINGS OF BIRDS¹

By Lieut. Commander R. R. GRAHAM, R. N.

GLOSSARY OF TERMS USED

- AIR STREAM.**—The flow of air felt by a bird or any part of a bird owing to its motion through the air.
- AIR-STREAM GRADIENT.**—The upward or downward slope of the air stream felt by a point on the wing of a bird in flapping flight, the angle of slope depending upon the proportion of vertical speed at that point to horizontal speed of flight.
- ASPECT RATIO.**—The proportion of length to breadth of a wing. Obtained in figures by dividing the length by the mean breadth.
- BARBICELS.**—Of a feather; the microscopic branches that spring from some of the barbules. Some are simple spines, others are hooked.
- BARBS (or RAMI).**—Of a feather; the branches that spring at an angle from the shaft, and, in mass, form the webs.
- BARBULES (or RADII).**—Of a feather; the minute branches that spring from the barbs. Some are branched, others not.
- BLADE.**—Of a wing or feather; the whole surface; i. e., of a feather, the two webs considered together.
- CAMBER.**—The curve of a wing between the leading and trailing edges.
- CORD.**—Of a wing or feather; the distance between the front and rear edges when in flying position.
- COVERT FEATHERS.**—The small feathers of a wing which cover up the gaps between the shafts of the flight feathers near their roots where they are devoid of barbs.
- CUTTING EDGE.**—Of a feather; a stiff, narrow form of front web, designed to cut the air; that is, to act without the support of another feather in front. Found along the whole front web of the first flight feather in all birds; but in other feathers only where their front webs are emarginated.
- EMARGINATION.**—Of a feather; the stepping down in width toward the tip, either of one or both webs. Only found in certain primary feathers of certain types of birds.
- FLIGHT FEATHERS.**—The principal feathers of a wing; i. e., the visible primaries and the secondaries.
- INCIDENCE.**—The angle between the blade of a wing or feather and the line of the air stream which it encounters at any moment. This angle determines the depth of the furrow a wing cuts in the air.
- LEADING EDGE.**—The front margin of a wing or feather in flying position.
- PRIMARY FEATHERS.**—The main feathers that spring from the hand of a bird's wing. In some birds the first primary is so small that normally it can not be seen. The second primary is then considered as being the first flight feather.

¹ Reprinted by permission from *British Birds*, vol. 24, Nos. 1, 2, 3, 1930, and the *Journal of the Royal Aeronautical Society*, vol. 36, No. 253, January, 1932.

SECONDARY FEATHERS.—The main feathers that spring from the forearm of a bird's wing.

SHAFT.—The horny quill which extends from root to tip of a feather.

SLOTS.—Are of two kinds, the wing-tip slot and the wrist slot.

SPAN.—Of a bird; the distance between the fully extended wing tips when the wings are at full stretch.

STALLING.—The process which occurs when an unduly large angle of incidence is used. It causes a sudden loss of lift and increase of head resistance.

TRAILING EDGE.—The rear margin of a wing or feather in flying position.

WEB.—Of a feather; one of the halves into which the shaft divides the blade.

WING LOADING.—The weight carried per unit of wing area with the wings fully extended.

I. SEPARATING WING-TIP FEATHERS

A noticeable peculiarity in the flight of a certain number of birds is the way their wing-tip feathers separate, both in flapping and in gliding flight. So wide do the gaps between the feathers become at times that the outer parts of the wings take on the appearance of hands with their fingers spread out. One's first thought about the matter is that there is probably nothing in it; that the feathers separate simply because they are feathers, and, as such, can not help themselves; but, on investigation, this turns out to be one of the most interesting of the many aspects of the flight of birds—interesting not only because it brings to light the infinite care and cunning that have been bestowed on the construction of their wings but also because it demonstrates the possibility of applying some of the lessons that birds can teach us to the design of flying machines, gliders in particular. When considering such questions we should always humbly remember that birds are the outcome of the law of the survival of the fittest through countless ages of flying, while we have been at it only for about 30 years.

It is fairly easy to explain why the wing-tip feathers separate, but the question of the purpose they may serve in doing so is more of a puzzle. As there appear to be several possible and plausible answers to it, I propose to put them down and leave those who are interested in the subject to judge how many, if any, of them are worth considering. Personally I believe that this separation serves different purposes in different types of birds and in different phases of flight and that it sometimes serves more than one purpose at a time.

The fact that the wing-tip feathers of some birds separate widely in flight, while those of others do not appear to do so at all, seems to be about the best clue to follow up. Among the smaller species, such as finches, warblers, tits, swallows, and thrushes, the peculiarity in question is not noticeable to any marked degree; the wings of these birds vary both in general shape and in the pointedness of the tips. It is only in a certain number of the medium and large sized birds that separation is really distinct. Of these, ravens, rooks, eagles,

swans, and game birds (pheasants, partridges, and allied species) are some of the more familiar. Without exception they have comparatively square or rounded wing tips, though the wings themselves are of various shapes.

Let us consider a group of birds of corresponding size whose feathers do not appear to separate much, if at all, such as the woodcock, snipe, duck, pigeons, cuckoos, gulls, and nearly all the sea birds. One could almost be sure that, except for their very tips, the feathers of some of these birds always remain packed together. In this group the wing tips are distinctly pointed, though, again, the shape of the wings varies considerably.

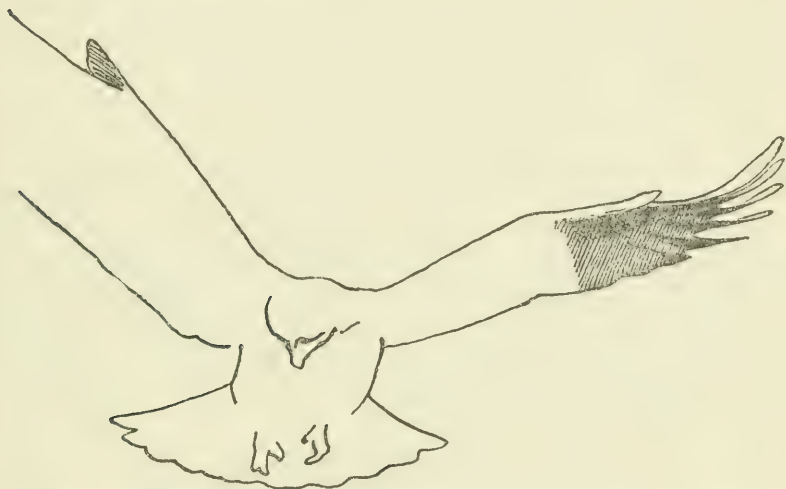


FIGURE 1.—A golden eagle about to alight. Only the tip of the wing is shaded to emphasize the incidence of the separated feathers. (From a photograph by Arthur Brook.)

As a preliminary basis to work on we might therefore suggest that separation of the flight feathers is more likely to be met with in big than in small birds and in birds that have squarish or rounded wing tips than in those that have pointed ones.

In view of the wide divergence between the speed of flapping of game birds and of other types that have separating feathers it would appear that the speed at which the wings are flapped has no direct bearing on the matter.

II. THE THEORY OF FLIGHT

Before going into the matter in detail, it is, perhaps, advisable to describe briefly the manner in which a wing derives power or "lift" from the air. First and foremost, it should be borne in mind that, just as a swimmer obtains forward motion by pushing water backward, so does a bird counteract gravity by causing air to move

downward. Secondly, it should be remembered that a bird seldom, if ever, beats the air downward, even in flapping flight. Instead, he makes his wings slice through the air and deflects it downwards, thereby obtaining an upward reaction.

Really, a wing acts on air in much the same way as a plough deals with earth; a curious simile perhaps, but true in so far as it cuts a furrow and piles up the displaced material on one side—of a wing, the under side.

The air which is displaced beneath a wing accounts for approximately one-third of the total force derived. The remaining two-thirds are generated on the top of the wing in a way that is not quite as simple. Taking again the simile of the plough: the furrow it cuts is, practically speaking, filled with air as soon as it is made; but the furrow cut by a bird's wing is made at such a speed that the air is unable to fill it immediately. There is nothing else to do the job, because the only other possible object, the wing itself, is being prevented from moving upward by the muscles that control it. So the furrow remains as a partial vacuum (for the air does manage partly to fill it) and follows the wing wherever it goes, so long as the speed and the angle of incidence are suitable. If the air were sufficiently fluid to fill the furrow immediately it formed, there would be no suction remaining to exert an upward force on the wing, so it is really the slowness of the air in moving down that is responsible for the force derived on the top of a wing.

The combined force, one-third from below and two-thirds above, is known as the total resultant force. It has been found to act at about 90° to the surface of the blade of a normal wing; therefore, by setting his wing at any particular angle, a bird can make it produce a reaction in whatever direction he requires, provided always that the air speed and the incidence are suitable. It is by holding the wing against this combined reaction of the air that a bird can defy gravity and, by suitable inclination of the surface, obtain forward movement.

Figure 2 shows roughly the lines which the two streams of air follow as they pass the wing. Where the lines are close together the air is under pressure, and where they open out there is tension between the air and the wing²; in other words, the pressure is less than that of the atmosphere. Observe that the flow of the upper stream is quite smooth, and that it flows at high speed close over the trailing edge of the wing.

When a bird wishes to glide more slowly, he must make his wings cut a deeper furrow in order to make up in quantity of air displaced

² Though it is technically inaccurate to consider the air pressures in this way, it is the simplest means of getting a clear view of what happens.

for the reduced downward velocity his wings are giving to it.³ This he does by increasing their incidence. That is all very well, and it works beautifully, but only up to a certain limiting angle, which, unless it is increased by some special means, is in the region of 15° . (These special means take the form of certain peculiar arrangements of the feathers akin to the Handley-Page slotted-wing device. They are of particular interest because they vary very much in different species of birds, and are therefore of great help to

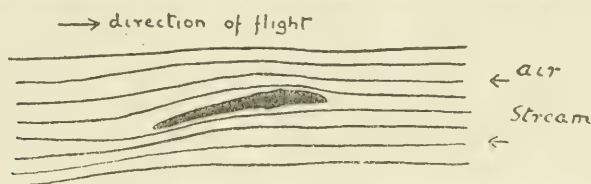


FIGURE 2.—The flow of the air-stream past a wing seen end on, in normal flight

anyone trying to arrive at an understanding of the differences in their flight.)

As the limiting angle of incidence is approached, the upper of the two air streams, being deflected more and more sharply downwards in its effort to fill in the furrow cut by a wing, finds increasing difficulty in turning the corner, until finally, and quite suddenly, it gives up the struggle and instead, just rushes on for a short distance and then turns, and, as it were, follows the wing. Thus the smooth

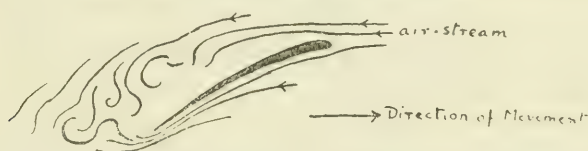


FIGURE 2a.—The flow of air past a wing seen end on, in "stalled" flight

flow of air over the top of the wing is broken down and the air-stream begins to form into little whirls, a process known as "bubbling." The bubbling is accentuated by the lower air stream, which, being no longer kept in place by the even flow of the upper stream over the trailing edge of the wing, is able to flow up and join in filling up the partial vacuum. (One can get a very good idea of what bubbling is, by dragging one's hand at an angle through water.) Figure 2a shows more or less what would be seen if the air stream were visible.

³ Speed is of the greatest importance, for by halving the speed a bird reduces the value of the force his wings are producing to one-quarter, unless he increases the incidence. In the same way he can quadruple the amount of force by doubling the air speed. The law in accordance with which this happens is that at such speeds as birds attain the value of the total resultant force varies as the square of the air speed.

The important thing to note is that though the air stream is still being slow in filling the furrow cut by the wing, it is now being slow in moving forwards and upwards, and the pull of the air on the wing is in the reverse direction—backwards and downwards. So now, a large part of the force of air reaction is in a backward and downward direction, instead of being at 90° to the wing surface; just what is not wanted as a rule. This state of affairs is known as a “stall,” and it always comes into existence when an unduly large angle of incidence is used, either in gliding or flapping flight.

An airplane whose wings are stalled commences to fall, owing to the lack of “lift,” and then to spin, on account of certain little-known aerodynamic laws. But, in some of the more modern types, this stalled descent can be controlled in such a way that, instead of spinning, the machine descends on an even keel. This is precisely what some species of birds can do by virtue of their separating feathers, as I hope to show in this article. Without this separation of the feathers they could not do it.

III. EMARGINATION

That nature had a definite purpose in view when she provided some birds and not others with separating flight feathers becomes appar-

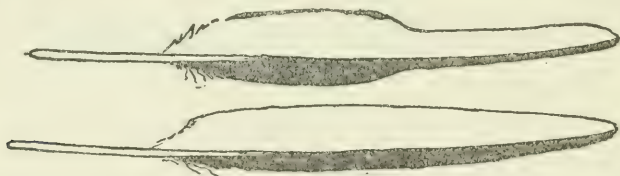


FIGURE 3.—Above, 3rd flight feather of a buzzard; below, of a golden plover

ent if the shape of such feathers is compared with that of corresponding ones taken from a wing in which separation does not take place. Figure 3 illustrates this comparison. Observe how the buzzard's feather (a separating one) is reduced in width from a broad base to a much narrower tip, not gradually, but in a distinct step; whereas the golden plover's (a nonseparating one) only narrows down gently the whole way. The feathers illustrated are taken from similar positions in the wing.

This stepping down in width, known to ornithologists as “emargination,” is always present in the feathers of birds that have separating flight feathers, sometimes on both webs of the feathers, sometimes only on the front webs, while in certain feathers in any particular wing it is confined to the rear edges. The terms “front” and “rear” are used here, rather than the usual “outer” and “inner,” because we are considering the wing in its working position, fully spread.

The emargination obeys certain definite rules. The front web of the first flight feather, the first visible primary, is never emarginated; where any marked separation takes place, the rear web is. Then, in some wings the front web of the second feather is the only other emarginated one, but in others varying numbers of feathers have steps in both webs—five appears to be the greatest number—while in all cases the hindmost feather that has a step has it only in the front web. The result of this arrangement is that when the wing is fully spread the outer parts of the feathers do not overlap and gaps or “slots” form between them as shown in Figure 4.⁴

For some reason, in the wings of certain species of birds nature has taken particular care that these slots shall be of fair width, even at their inner extremities, where they might reasonably be expected to form very acute angles, owing to the fact that the feathers radiate from a fairly small center, the hand of the wing. She has achieved

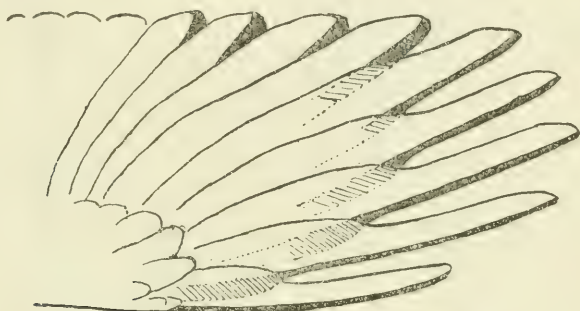


FIGURE 4.—Right wing-tip of a buzzard seen from below. The front webs of the feathers are drawn black for emphasis

this result by making the webs of the feathers narrower just outside the steps than they are farther out toward the wing tips. The effect is that the margins of the slots are more nearly parallel than they would otherwise be and the inner extremities squarer (fig. 5).

Though not found in quite all emarginated feathers, this remarkably careful shaping is often to be seen in the feathers of birds with well-developed slots. Its purpose has perhaps something to do with the “drag” that would be induced by air rushing at high speed through a narrow space, with silence in flight, or with the need for a good flow of air throughout the whole length of a slot in order that the full benefit may be derived from it. The slots in the wings of pigeons are good examples of the type that lacks this careful shaping, and these birds are noticeably more noisy in flight than many others. (For comparison see fig. 36.) It also looks as if

⁴ In some birds the emargination of the rear webs is very indistinct, particularly in the feathers that form the hindmost slots. The pheasant's wing is a good example.

this careful shaping is designed to prevent wear on the edges of the feathers, for it must cause the whole slot to open at almost the same moment, instead of the separation starting at the tip and working inward, with consequent chafing.

IV. BENDING AND TWISTING OF SEPARATED FEATHERS

Figures 6 and 7 show examples of separation. These birds may either be making a downward beat or just gliding, the camera does not tell us for certain, but for the present purpose that does not mat-

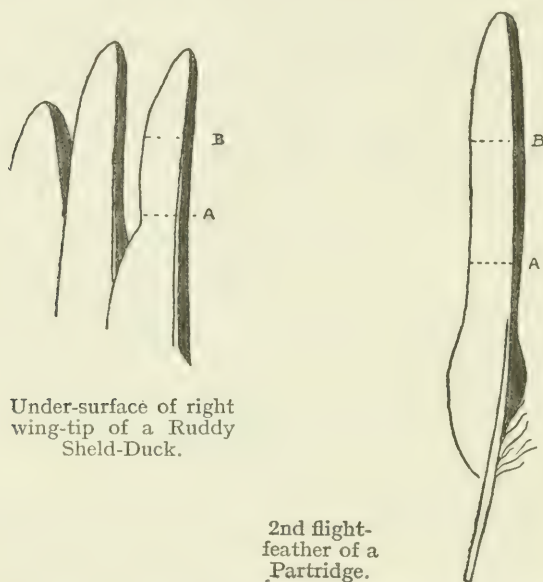


FIGURE 5.—Typical examples of emargination being greater near the step than at the wing-tip. Both feathers narrower at A than at B

ter. All that is required is to know that the air stream is striking the wings from below. That it is doing so is quite evident.

In both birds the separated feathers are distinctly bent in an upward and forward direction, and at the same time twisted in such a way that their leading edges lie lower than their rear or trailing edges. First consider the twisting alone. Since no feather has muscular power in itself, this effect must be due to the reaction of the air which the feathers are displacing. The wing itself is held or moved by its owner in such a way that the air stream is striking it at an angle from below and in front, the angle of incidence. The roots and the overlapping parts of the feathers are embodied in and supported by this main part of the wing, but the separated outer portions lack mutual support and are to a certain extent at

the mercy of the rush of air which they feel, the air stream. Having wider webs behind than in front of their shafts, the feather blades can not help twisting somewhat into line with the upward-slanting stream, because it has more effect on the broad than on the narrow webs. Thus the angle at which the separated blades of the feathers lie to the line of the air stream becomes less than that at which the main wing lies. This is a matter of decided advantage to a bird, because it means that he can afford to put his wings at such a large angle of incidence that, though they may stall and become comparatively ineffective, he will yet be safe, because their



FIGURE 6.—A marsh-harrier descending. (From a photograph.)

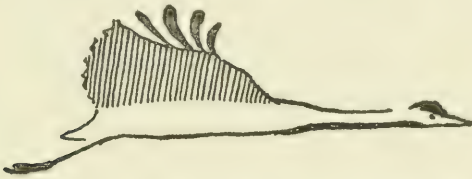


FIGURE 7.—The right wing of a crane seen from below. (From a photograph lent by Col. R. Meinertzhagen.)

very important outer parts (important because they are most favorably situated for controlling) will automatically remain effective and in an unstalled condition. Further, they will remain so even if he increase the incidence of the main wing to several degrees beyond the stalling angle.

That the separated feathers should bend upward is only natural since the airstream is striking them at an angle from below, but that they should also bend forward seems a trifle odd. The explanation is that they are yielding to the reaction of the displaced air, which acts, according to the accepted theory of flight, in a direction approximately at right angles to the surface of their blades; and after they have been twisted, that direction, as can be seen in Figure 8, must be upward and forward relative to the parent wing. While the slots

are opening, each whole feather, pivoting about its root in the hand of the wing, is dragged forward by the force reacting on its twisted tip. When the limit of that movement has been reached, the flexible separated tips bend forward, still in obedience to the reaction on the twisted parts of the blades. The bending of separating primaries

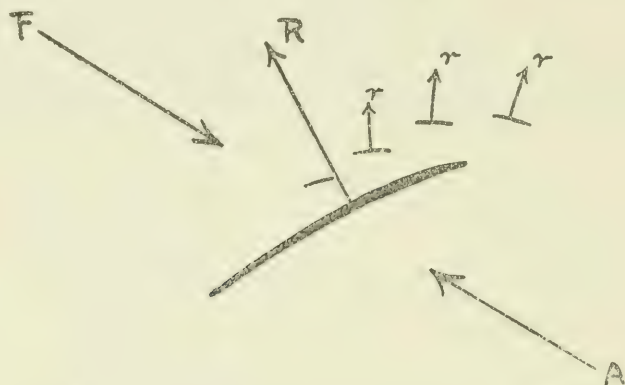


FIGURE 8.—Diagram illustrating the reason for the upward and forward bending of separated feathers

A, direction of air stream; F, direction of movement of the wing; R, total resultant force on the main wing; r, total resultant force on each separated feather-blade.

adds greatly to the smoothness of the flight of short-winged birds. The reaction in each wing beat is, as it were, cushioned. Instead of commencing and ending sharply, it gradually rises to a maximum, and gradually dies away as the feathers straighten themselves after the termination of the down beat.

V. THE SINGLE WING-TIP SLOT

A good example of the simplest development of the slot is found in the wings of some forms of duck, the teal (*Anas crecca*) for instance. Figure 9 shows the first four flight feathers of a teal's wing.



FIGURE 9.—Under-surface of right wing-tip of teal

Number one feather's front web is very narrow and very stiff from tip to root; a suitable form for taking the first blow of the air as the wing cuts through it, and for dividing the stream ready for its passage over and under the wing surface that lies in rear of it. The front web of number two feather is of identical construction, but only for a distance of $1\frac{3}{4}$ inches (AB in the figure), measured inwards from the tip; that is, as far as the step in the web. Inside that point it resembles the front webs of all the other primary feathers that lie behind it in being comparatively

broad and flexible, and only suited for working at an angle to the air stream with the shield and support of another feather in front of it.

This indicates that the outer part of number two's front web is a "cutting edge," and that it serves a similar purpose to the whole of the front web of number one; which, in fact, it does, for when the slot is open it is left isolated through the bending up of number one, to face the air stream on its own. (Fig. 10.) Number two feather, itself, does not get bent or twisted, because its rear web is supported above and behind by the front web of number three, there being no slot between these two. And the same thing stands for all the other feathers in the wing; they give each other mutual support, which prevents any part of them from being twisted round by the force of the air stream.

The teal's cutting edge is typical of the cutting edge of all birds, though there is considerable variation in proportionate width in different species. There are other interesting variations, too: In most game-birds and duck, for instance, the cutting edges appear to have



FIGURE 10.—Duck making a down-beat. The separated tip of the first flight-feather has bent upwards and forwards. (From a chronophotograph in Marey's Movement. Owing to the peculiar form of photography, the series must be read from right to left.)

a biconvex section, such as that used in the modern high-speed aeroplane wing, and are about twice as thick in section as the rear webs directly behind them. Where they are so thickened the under-surfaces of the feathers have an unmistakable silvery appearance. Then there is the wing of the short-eared owl (*Asio flammeus*), in which the one short piece of cutting edge is easily distinguished from all the other leading edges by its comb-like appearance; no doubt this is something to do with the general "muffling" of the typical owl's wing. In the wing of a griffon vulture (*Gyps fulvus*) the cutting edges are much more curved down than those of many other birds. This, one suspects, may have something to do with the high lift value required by that bird when soaring at low air-speeds. In fact, cutting edges make a very interesting study in themselves alone, and I have mentioned only a few of their peculiarities.

When the single slot in the teal's wing is open, and the isolated tip of the first feather has been bent and twisted by the air stream, a section taken through the wing at the midpoint of the slot would look something like Figure 11. The resemblance of this to a slotted airplane wing (fig. 12) is quite evident.

Quoting from the Handley-Page handbook on the subject:

The slot in the wing, extending along the leading edge and formed between a small movable winglet and the main wing itself, prevents a breakdown in the airflow over the plane at large angles of incidence, and so permits the wing to continue lifting at angles at which stalling would previously have taken place. The stream of air introduced at high speed through the slot from the



FIGURE 11.—Probable flow of the air-stream through a single wing-tip slot

A, section of the tip of the first flight-feather; B, of the main wing directly in rear of it.

under surface has the effect of smoothing out the flow of air over the plane, and keeping it in contact with the upper surface, delaying the incidence of the breakdown of the airflow to angles so large as never to be encountered in actual flight.

In other words, it appears that the separated part of the first flight feather of the teal gives the air stream a preliminary downward nudge, so that when it arrives at the downward curve on the top of the main wing it is able to cope with the change of direction, and flow down over it smoothly, without burbling and causing a stall. If this really is the case, we can presume that the part of the wing which is situated behind the slot in the teal's wing, does not stall immediately the incidence becomes so high as to cause the rest of the wing to do so, and

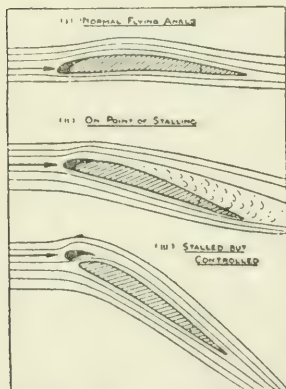


FIGURE 12.—Diagram illustrating the action of the Handley-Page slot. (From the handbook issued by that firm.)

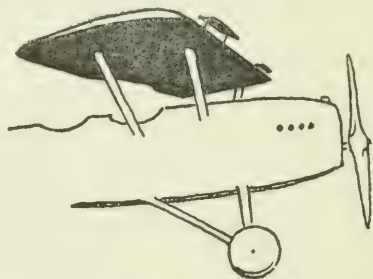


FIGURE 13.—The appearance of a Handley-Page slot in the open position

that it maintains the value of the lift it is giving, while the main part of the wing is producing "drag" rather than lift.

This excellent property of the wing tips, given to them by the slots, can be of use to a teal in several ways. Here is an example. Think of him as he glides down to alight on a flat-calm day, when there is no wind which he can use (by facing it) to reduce his speed sufficiently to let him touch the water without capsizing. His wings have got to produce the "braking effect" required and yet main-

tain their "lift,"⁵ and they are not of the most suitable type for the work, because the teal has far higher wing loading (smaller wings for his weight) than most birds.

The production of a big braking effect requires a strong backward-inclined reaction from the air; that means a large angle of incidence (fig. 14), almost certainly larger than the stalling angle of the wings. In these circumstances, even if they do stall, it does not matter much as regards "braking," for though the total resultant produced may fall in value, it will be all in the right direction—backwards. But it does matter from the point of view of "control," and that is where the slots come in. They insure that part, at least, of the wing, and that the most important part for controlling, will not stall. So this preliminary glide down toward the water appears to develop into a stalled, yet controlled descent, with the body in a horizontal position, or even slightly tilted up in front,

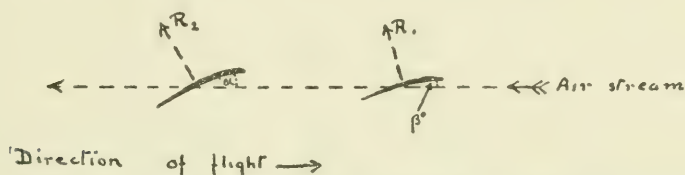


FIGURE 14.—Diagram showing how braking effect increases with the angle of incidence. Force R_2 points more backward than R_1 because angle α is greater than β

not inclined downwards as in a true glide or dive. One can often see commoner birds, notably rooks (*Corvus frugilegus*), carrying out the same maneuver.

Having, in this way, reduced his speed somewhat, the teal finds that the controlled stalled descent is going to bring him on to the water with too much downward speed for comfort. To overcome this trouble he starts flapping his wings, at first with very small strokes, little more than a quivering of the wing tips, then gradually increasing the movement until it is almost as vigorous as when he is getting under way at the beginning of a flight. The true reason for the need to start flapping is that he has reduced the speed of the air past his wings so much that they are unable to derive from it the necessary force to obtain braking effect and "lift," and that therefore the wings themselves must be moved to increase the lift. The movement which has to be made up for is a forward one, so the wings must be moved forward; that means a forward and backward flap, which is the form of flapping flight often used by birds when alighting on windless days.

⁵ Probably the spreading of the webbed feet, ready to continue the "braking" in the water, assists the wings slightly in this.

Actually the beat is not horizontal, but it is not far from it. It is an approach toward hovering flight, and, as can be seen in Figure 15, hovering birds do use this nearly horizontal beat, at any rate in calm weather. The body is tilted up at an angle which brings it into nearly the same position with relation to the beating wings as in normal flapping flight, thus doing away with the need for special

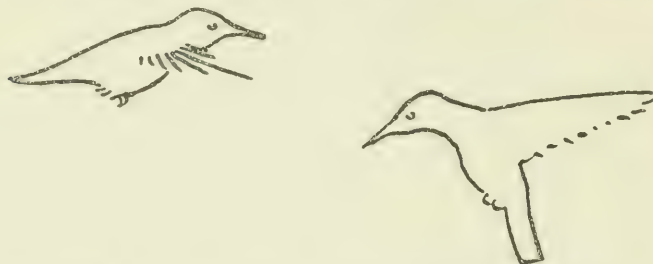


FIGURE 15.—Humming birds hovering. (From photographs.)

joints and muscles. This typical attitude, assumed by all forms of ducks (and indeed most other birds) when alighting in calm weather, will be recalled by Figure 16. Incidentally this attitude must in itself cause a certain increase in the braking effect caused by the passage of the body at an angle through the air, and must also reduce the tendency to capsize on touching the water.

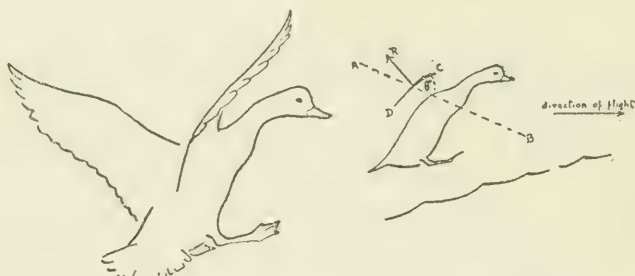


FIGURE 16.—Left, typical attitude of a duck while alighting. Right, diagram illustrating the action of a duck's wing in the down or forward beat while alighting. The section of wing shown is near the body. Farther out toward the wing-tip, the air-stream would twist the wing so that the angle of incidence would be smaller

The slot comes in very handy in this proceeding, too. Imagine a point on the teal's wing traveling, during the forward stroke, from A to B (fig. 16) and producing a force from the reaction of the air, roughly, in the required direction R. To do so, the surface of the wing must lie at right angles to that direction, that is, in position CD. The air stream felt by the wing during the stroke is, practically speaking, in the reverse direction to the stroke, i. e., from B to A (because the bodily forward movement of the bird is now

so low as to have but little effect upon it). That means a large angle of incidence and the need for the slot once more to prevent the stalling of the wing tips.

It is worth noting here that the wind tips are doing nearly all the work, because the inner parts, being close to the body, can not be flapped through an arc large enough to produce the air speed which is essential for the production of force from the air; therefore, it is doubly important that the best should be got out of the tips. The slot allows this to be done by permitting the use of a large angle of incidence.

VI. OPENING AND CLOSING OF WING-TIP SLOTS

The study of how wing-tip slots are opened and closed is most interesting, because it discloses the presence in a bird's wing of one of the most cunning, economical, and amazingly effective devices imaginable.

A bird at rest can spread its wings sufficiently for the slots to open fully; one can see the great birds of prey at the zoo doing it almost any day. That is evidence that birds certainly are provided with the necessary muscular equipment for the movement, but it does not follow that they use it for that purpose in flight. Here is evidence that they do not. If one takes the wing of a freshly-killed rook, for example, spreading it so that the feather tips are just not separating, and holding it at a large angle of incidence (in the nature of 25°) to the draught from a powerful electric fan, the air stream will open the slots by blowing up the broader rear webs of the emarginated parts of the feathers. If, on the other hand, this wing is held with the feathers loose and not pressed together, it can easily be spread so far that gaps appear between the broad parts of the feathers on the body side of the steps in the webs, as in Figure 17. That is, one can overspread it.

That is how a bird at rest appears to stretch its wings—with the feathers not pressed together. But, if one personally takes the place of the air stream which would be met in flight, and holds the wing so that each feather is pressing up against that which overlaps it, and then one tries to spread the wing as far, it will be found that a brake is quite suddenly put on which seems to lock all the emarginated feathers in the "slot-fully-open" position. Only by tearing apart the barbs of the front webs, where they still overlap the rear webs, can one effect any further spreading. The secret of

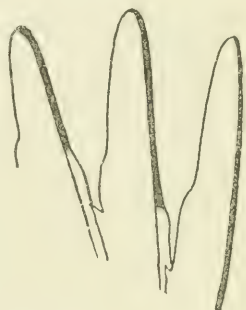


FIGURE 17.—Lower surface of a song-thrush's right wing-tip, with the slots more than fully opened. Gaps appearing beyond the inner limits of the slots and barbs being torn apart from each other are shown

this braking effect appears, at first, simply to be friction between specially-shaped roughened areas on the feathers, which come into contact at the critical moment. The difference between the texture of the upper surface of a feather in one of these areas, and elsewhere, can quite easily be seen with the naked eye. Figure 18 shows the extent of one of them in a typical emarginated feather.



FIGURE 18.—Upper surface of a slot-forming feather in a griffon vulture's wing. The dotted line shows the limits of the friction area

But examination of the surface with a microscope indicates that the roughness is more than a friction surface; it shows that the effect is brought about by thousands of tiny hooks which stand out above the main surface, and engage with the ribbed underside of the broad part of the overlapping feather. These hooks are really an extension of the normal mechanism that holds the barbs of a feather together.

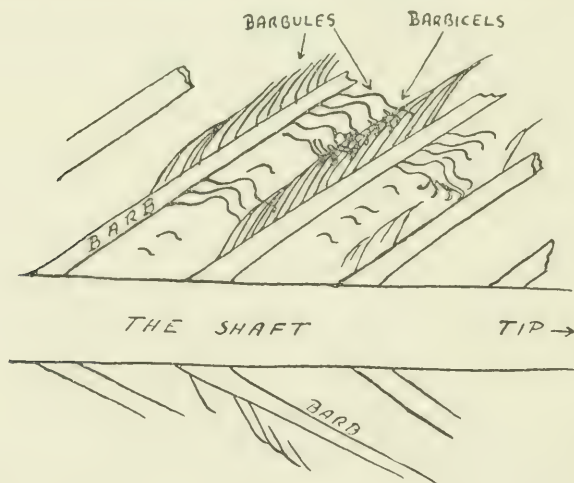


FIGURE 19.—Construction of the upper surface of a slot-forming feather from a griffon vulture's wing. This section is outside the friction area. Only a few of the branches have been drawn in

From the shaft of any feather the barbs branch off at an angle inclined toward the tip. From them the barbules (Fig. 19) spring. Those that are on the side of the barbs nearest the root of the feather are simply spines that lie in serried ranks, springing at a fine angle from the barb, but those that are on the side nearer the tip are much more complex in structure. Figure 20 shows a typical example of

their normal development. The hooks are designed to engage with the spiny barbules on the next barb toward the tip of the feather.

Both hooks and spines are very flexible, and that is why a feather can be made to return to its proper tidy state after one has withdrawn the hooks from their hold on the spines by rubbing it up the wrong way, as, for instance, when using the feather as a pipe cleaner—unless, of course, the pipe is a very foul one; then, nothing will avail.

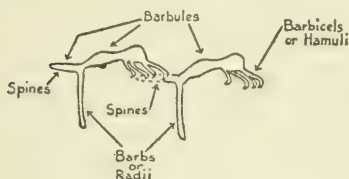


FIGURE 20.—Section through adjacent barbs outside the friction area



FIGURE 21.—Section through adjacent barbs in the friction area

Figure 20 is a sectional view of two such barbs with the hooked barbicels branching downwards off the tip-side barbules. In the friction area of a slot-forming feather, however, the tip-side barbules do not terminate at the point where the last barbicels branch off downward, but go on, with a sharp upward bend, as shown in Figure 21, and bear several more hooked barbicels.⁶ These give the friction area its typical rough appearance, and their purpose is to hook on to the next overlapping feather and prevent overspreading.



FIGURE 22.—Section through the unmarginated parts of adjacent slot-forming feathers with the friction area not engaged



FIGURE 23.—As in Figure 22, but here the friction area of the lower feather is just coming into operation at Z. AB is the total breadth of the friction area

During the earlier stages of the spreading process the protruding underside of the shaft of an overlapping feather rides over the friction area of the lower feather and prevents its engaging (this phase is shown in Figure 22); but at the critical moment, when the slot is approaching the fully open position, the sharply curved-down leading edge of the upper feather arrives at the forward margin of the friction area of the lower one, and the hooks engage, gradually locking the feathers together, except for a certain amount of "give" due to the springy nature of the barbules and barbicels. Figure 23 shows a

⁶ Only a few wings have been examined for this peculiarity, but it is suspected that all slot-forming feathers possess it to a greater or less degree.

sectional view of two feathers in this position. The narrow parts of the feathers outside the steps in the webs are, of course, in the fully separated position at this final stage of the spreading of the wing. The arrow marked Z shows where the friction is greatest.

This friction business does not apply only to slotted wings, for ordinary ones, such as those of the swallow (*Hirundo rustica*), woodcock (*Scolopax rusticola*) and gull, display varying degrees of this locking tendency at the moment when the tips of their feathers are about to separate. The secondary feathers, and also the unslotted primary feathers of birds that have slotted wings, are subject to it as well.

In most wings the engagement of the friction areas is made the more certain by the upward curl of the rear margins of the feathers, which assists the air pressure to bring the two surfaces into contact.

One other interesting point about the device is that the front edge of the front web of an emarginated feather is always sharply curved down in the unemarginated part, but in nearly all such feathers (the vulture and perhaps some other soaring birds are exceptions, as was mentioned before) it is to all intents and purposes flat from the step outwards to the tip, that is to say, along the "cutting edge." This peculiarity is quite helpful when one is trying to measure the total length of cutting edge that any wing possesses. The reason for this difference is that inside the step, the front web has to do the work of digging down into the friction area of the feather in front of it, and working as a limit stop to prevent overspreading; but, outside the step, its purpose is simply to cut the air.

In a table to be given at the end of this paper will be found the proportion of cutting edge to length of wing in a number of representative types of birds. It is there called the "slot factor."

The apparent action of the opening of the wing-tip slots can now be summed up as follows: When the wing has spread so far that the emarginated parts of the feathers are about to separate, the air stream, if it has sufficient incidence, forces the broader rear webs of the separated parts of the feathers upward, so that the blades are twisted toward the line of the air stream. In this manner the incidence of these separate feathers becomes less than that of the main wing; and, consequently, the direction of the force reacting on them is more forward. The result is that they all move forward and the slots open wide. At the same time the tips of the feathers bend upward, owing to the absence of mutual support. At a certain moment during this process the individual forward movement of each feather is checked and finally stopped by the arrival of the curved-down leading edges of the still overlapping parts of the feathers at the front margin of the friction areas of the feathers

which they overlap. Air pressure from beneath helps these surfaces to engage (the stiff down-curved front webs are not affected by the suction from above), and any further forward movement takes the form of spreading the whole wing, because all the primaries, and to a certain extent the secondaries, are then practically locked together.

The need for this automatic limit stop to prevent overspreading is strong evidence that the final stages of the expanding of a wing, at any rate a slotted one, are done by air pressure and not by muscular force, except in so far as the breast muscles are preventing the wing from flapping upwards, or are actually pulling it down, as in flapping flight.

This description of the opening process of the slots in a multislot wing applies in limited degree to a single-slot one.

VII. THE MULTIPLE WING-TIP SLOT

One outstanding difference between the multi- and the single-slot wing is that in the former the slots extend right across the wing from front to rear. They must, therefore, serve some purpose additional to that of simply delaying the moment at which the wing surface in rear of them stalls. With the notable exception of the game birds, most of the bigger birds which have a high development of the multislot wing, such as rooks, ravens, eagles, buzzards, etc., are in the habit of soaring, or at least of gliding very slowly if they do not actually soar. As any experienced airman knows, the control of lateral balance becomes increasingly difficult as air speed is reduced, so one is led to suspect that there may be some connection between slots and lateral control at the low air speeds used by soaring birds.

Think of one of these birds as it glides slowly, with wings set at a comparatively large angle of incidence,⁷ in order that it may make the best use of the low air speed. If the tips of the wings were solid (i. e., unslotted), and the bird wanted to alter its lateral attitude (put on "bank"), a small change of the incidence of one wing tip would only have the effect of altering the lift slightly on that side and of tilting the bird a little one way or the other; but if the feathers in that wing tip were already lying near the angle of "no lift" (as they would be if the wing were slotted), a small alteration of their incidence would either double the lift they might already be giving, reduce it to nothing, or actually reverse the direction of force and convert it into a downward reaction. In other words, a small movement of the control surfaces of a slotted wing has the

⁷ Sir G. T. Walker, in his paper on this subject, which appeared in the *Journal of the Asiatic Society of Bengal*, in 1924, makes out this incidence to be in the region of 28° for a soaring vulture.

same effect as a large movement in an unslotted one; and, further, a slotted wing tip can go on giving lateral control at far greater angles of incidence of the main wing than a solid one can. It is the automatic twisting of the emarginated parts of the primary feathers toward the line of the air stream and the angle of "no lift" that achieves this desirable result.

There is a parallel to this controlling device in a certain man-made flying machine called the "pterodactyl"^s (the word means "wing fingered"). It is really, with all due respect to its designer, only an experiment as yet; but it may well be the prototype of big things to come, for it can be made to perform efficiently in the air at lower speeds than can be used with any other modern fixed-wing aeroplane. Its best trick is the same controlled stalled descent as was described

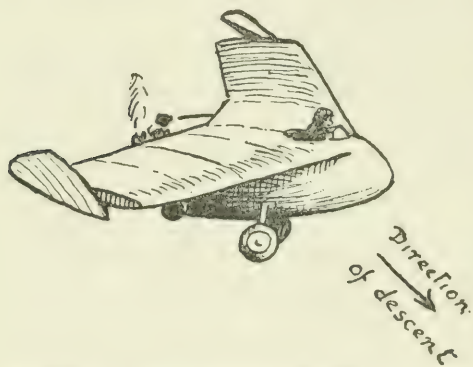


FIGURE 24.—The Pterodactyl tailless monoplane.
A sketch taken from a photograph to show the position of the controllers in a stalled descent^s

on page 281, with this small difference, that, in the pterodactyl, the controlling surfaces at the wing tips are not twisted toward the line of the air stream by means of air reaction; instead, they are moved by the pilot himself. They consist of swiveling flaps which, in form, are prolongations of the wing tips, and so have nothing in front of them, as the ordinary aileron has, to disturb the flow of the air

before it reaches them. They can be moved, like ordinary ailerons, in opposition to each other, by means of sideways motions of the control stick; but they can also be made to move together by pushing the stick backward and forward. Thus, when a controlled stalled descent is being made, the pilot, by pulling the stick back, can turn both flaps so that their front edges are lowered and their trailing edges raised, a movement which brings them into line with the air stream. Then, if lateral control is required, sideways movements of the stick will make them work like normal ailerons, in opposition to each other.

Figure 24 shows what the pterodactyl looks like when it is carrying out such a flight. The fact that it is tailless has no bearing on the present discussion; but it may be as well to say here that the control flaps, being set so far back on the machine, can be used in

^sThe pterodactyl described has been superseded by a new type (1931) whose control surfaces are not designed to operate in the manner described.

the place of the elevators of a normal tail when they are moved in conjunction.

No doubt nature, having feathers to work with in place of the sheets of metal or fabric which we use, finds it more economical to employ a number of small surfaces for controlling than a single large one, such as the controller of the Pterodactyl; but it is just possible that investigation of the matter might reveal something of use to aircraft designers. A comparison between Figures 24 and 6 is illuminating in this respect.

Figure 25 illustrates another way of looking at this antistalling effect of the multislot wing tip. It should be considered in con-



FIGURE 25.—Section showing the probable flow of the air stream through the wing-tip of the eagle in Figure 1^a

nection with Figure 1, as it is meant to be a diagrammatic sketch of a section taken through the separated wing tip feathers of the left wing of the eagle⁹ shown in Figure 1. The dotted arrows represent the probable flow of the air stream. They are drawn by guessing, in the light of our present knowledge of the behavior of air, at the way in which one would expect the air stream to behave on meeting such an obstacle as this slotted wing-tip.

Working backwards from the first feather, each blade in turn deflects the air stream in a downward direction, so that the one behind it does not have to twist through such a large angle to set

^a See footnote 2 on page 272.

⁹ Some years ago Mr. Handley Page, without knowing that this type of slot was to be found in birds' wings, designed and tested a model, having 7 slots, arranged in much the same way. He found that it increased the maximum lift by 250 per cent at an angle of 42°, as compared with the unslotted wing.

itself at a similar angle of incidence. In this way the direction of flow of the air stream is changed step by step through a greater angle than the stalling angle, without the burbling that would certainly occur if the attempt were made to do it all in one act.

Each feather is acting for the benefit of its "next astern" in the same way that a Handley-Page auxiliary winglet does for an airplane's wing; while it is, at the same time, producing a useful reaction in an upward direction, with either a slightly backward or slightly forward inclination, depending upon its position in the wing.

The reason for the bending up of separated feather tips has been discussed, but the question whether they serve any useful purpose in so doing still remains. There can be little doubt that when so bent they improve stability at low air-speeds. The surfaces of the blades of the feathers, instead of facing upwards and downwards, point more or less sideways, and so they become little keel surfaces, and, placed as they are at the ends of the long levers of the wings, their effect must be considerable. Really, they serve the same purpose as the "dihedral angle" (upward inclination of the wings from root to tip) used by aircraft designers to give lateral stability.

VIII. THE RELATION BETWEEN SLOTS AND THE SHAPE OF WINGS

It was observed at the beginning of this paper that slots are not particularly noticeable in the wings of small birds in flight. The reason for this is that the eye fails to see them because they are very small, and the wings usually move at a great speed. The truth is that many of the small birds are very well equipped with slots. A blue tit, for instance, has five; a song thrush (*Turdus philomelos*) three; the robin (*Erithacus rubecula*), tree creeper (*Certhia familiaris*) and long-tailed tit (*Aegithalos caudatus*) have four; but in none of these birds is their development so marked as in some of their large relations. Figure 26 shows two views of a thrush's wing with its slots fully opened, and Figure 27 similar views for comparison of the unslotted wing of a swallow at full spread.

As a rule, the slots of small birds are formed more by the emargination of the front webs of the feathers than of the rear ones, but these rear webs are usually so thin and flexible that they must be very easily persuaded to blow upwards, in such a way as to clear the leading edge of the next feather behind. In molted feathers, one often finds that the trailing edges have been worn to shreds opposite the emarginated front web of the next feather in rear by continual engagement and release with it.

Small birds probably derive a certain improvement in lateral control from their slots, but they do not often appear to carry out the stalled descent, and they certainly never do anything in the

nature of soaring; they use a quick flap for a great part of their time in the air. Bearing this, and the somewhat different construction of their slots, in mind, we might do worse than try to find some other advantage that they may derive from them.

All small birds that are well equipped with slots possess comparatively short, square-tipped wings; just the opposite in shape to those of the few that have no slots at all; and the slots seem to vary in number and development so strictly in accordance with the shape of the wings that one might almost formulate a law governing the matter.

Compare the wings of the smaller birds among those shown in Figure 28. The swallow's is the longest and thinnest (relatively) and has no slots, though the tips of the first two flight feathers are per-

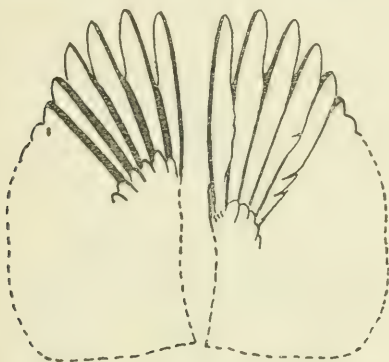


FIGURE 26.—Upper and lower surfaces of the left wing-tip of a song thrush

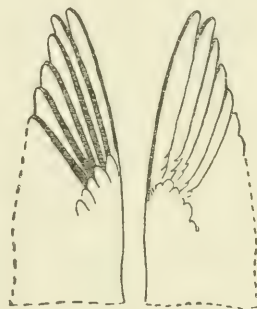


FIGURE 27.—Upper and lower surfaces of the left wing-tip of a swallow

mitted by the friction areas just to separate for a distance of about half an inch inwards from their points (fig. 27). Then comes the pointed wing of the starling, with two very short slots, and of the quail with about the same development. The latter's wings are comparatively long and narrow. The wryneck has exactly the same length of slot (1.2 inches), but that is relatively a better equipment, because its wing is 1.3 inches shorter than the quail's, yet of the same breadth. The wheatear, with its much broader and squarer wing, has three well-developed slots, as also have the square-tipped wings of the goldfinch and the thrush.

Here we seem to have an indication of the use of slots in the wings of small birds. It has long been known that the ideal airplane wing, from the point of view of "lift" alone, is one of infinite span, because such a wing, if it existed, would have no tip over which the air could escape sideways. Air, like other things we know, will avoid doing a job of work if it possibly can. Some of the air underneath a wing, instead of lifting a bird by allowing itself to be forced downwards by

the action of the wing, will slide out sideways,¹⁰ or even move upwards over the wing tip into the region of reduced pressure to join forces with another stream of air that is doing no good. This other stream



FIGURE 28.—Wings of a number of representative types of birds in fully-spread position. All are reduced to a common size for the sake of comparison

consists of air that is moving in sideways to assist in filling up the partial vacuum on the top of the wing.

¹⁰ The reason in technical language is that a gas which is compressed will tend to expand equally in all directions. By the same token it will tend to flow into a space where there is a reduced pressure; that applies to the top of the wing.

All this air that is moving sideways and upwards constitutes a waste of energy, because the only way a wing can obtain lift is by causing air to move "downwards." The broader a wing tip is, the greater will be the amount of air that thus tends to circulate around it, and the less efficient the wing will be.

In Figure 29 the rectangular shapes A and B represent two wings of equal area, but A is three times as long as B, and therefore one-third of its breadth. Suppose that a particle of air strikes the leading edge of wing A at point X. It endeavors to escape sideways from the pressure, but fails to do so before reaching the trailing edge at Y.

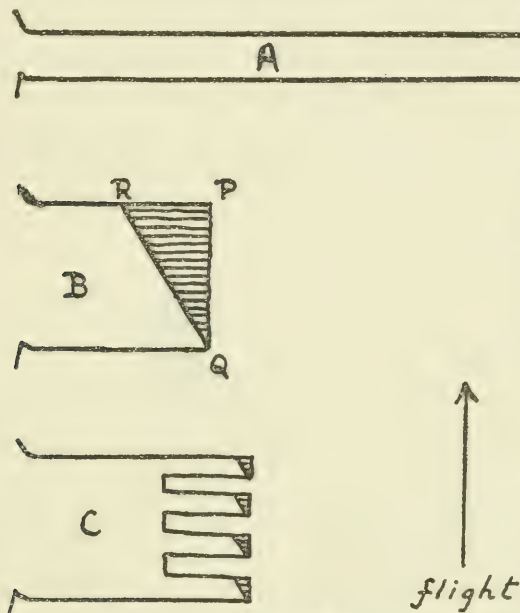


FIGURE 29

That means that the wing has got full lifting value out of it; but any particles that strike the leading edge outside point X will make good their escape without completing their job, so we can suppose that the area affected by wing-tip air spill is the triangle XYZ.

In wing B we might reasonably expect this area to be far larger (the triangle RQP) with a correspondingly greater loss; but if the tip is split up into a number of narrow winglets (keeping the total area the same), as in wing C, the affected area will consist only of the sum of the little shaded triangles in wing C, and that is a good deal smaller than RQP. That is what nature appears to have done to the short, broad wings of birds that can not afford to have long, narrow ones. The actual result is that circulation of air from the lower to the upper surface of the wing-tip is reduced.

It is interesting to note that the slotted areas of a good many of the wings shown in Figure 28 bear a distinct resemblance to the affected areas of wings A and B.

But why should we confine ourselves to small birds in considering this theory? Surely all birds that have separating wing-tip feathers must derive a certain amount of this benefit from them. The idea is supported by the fact that some of the really big birds that have long and narrow wings, compared with, say, a wheatear, are well supplied with slots. Vultures, cranes, and swans are good examples (fig. 30). Now compare the shape of their wing tips with those of the big birds that have no slots, the sea birds; the unslotted wings are, without exception, the more sharply pointed. Square tips are large tips, and the loss from them will be large unless they are slotted.

The reason why some birds, and not others, can afford to have pointed tips on their wings is not too clear, but it seems that a



FIGURE 30.—Left, crane; right, swan. (Sketched from photographs)

pointed tip must be longer than a square slotted one to have the same value; and whereas a bird that always flies in the open, such as a sea gull or a swallow, will not find that his long wings get in the way, one that lives among trees and bushes, and other things that obstruct the air, if so equipped, would find them a decided encumbrance.

So the root of the matter would appear to be this: That if his method of living will permit, a bird will have long, narrow, pointed wings of efficient airfoil shape because that is the nearest he can get to the ideal wing; but if he must have shorter ones to suit his environment, he can not afford to have them pointed, because such a shape would deprive him of some of his wing area; therefore, in order to prevent the great waste of surface that the spilling of the air over a broad wing tip occasions, he must have it split up into a number of small airfoils of efficient shape.

Incidentally, this "shaping" of the wing is known in aeronautical circles as the aspect ratio. A long, narrow wing is said to have a high aspect ratio, and a short-broad one a low aspect ratio. The

ratio is length divided by breadth, so if one wants the aspect ratio of a bird's wing, the mean breadth must be taken. Some aspect ratios are given in the table at the end of this paper.

Game birds, such as the partridge, pheasant, and blackcock, are excellent examples of the type that can not afford to have long, narrow wings. Instead, they have multislotted, broad, square-tipped ones. Blackcock and pheasants actually have six slots in each wing, and proportionately these slots are among the longest of any that are found in British birds.

Another factor which probably influences the shape of the wings of these birds is their habit of lying close when disturbed, and then getting up with tremendous acceleration. Long wings requiring a big sweep, with slow strokes, would get in the way, and would permit the acceleration to die away on the upstroke.

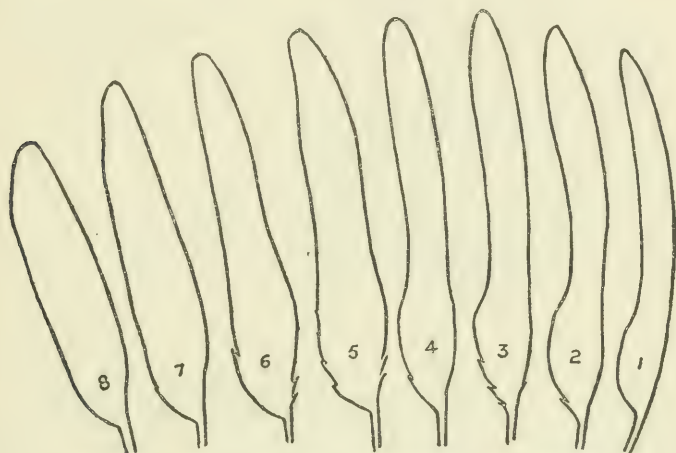


FIGURE 31.—The first eight flight feathers of a partridge

IX. SLOTS IN FLAPPING FLIGHT

Archibald Thorburn's excellent pictures of game birds in flight and many others, have made everyone familiar with the appearance of their wings, with their many-fingered tips. Figure 31 shows the shape of the individual flight feathers of a partridge's wing, and Figure 32 how they fit together and form the well-marked slots. One should not be too sure that the action of this type of slot is quite the same as that described already, because the broad parts of the webs, inside the steps, are mostly so very short that they can not have the same power to limit the separating of the feathers as have those of a buzzard, for instance (fig. 4). This type of stepping down is known to ornithologists as "basal emargination."

The extreme squareness of the wing fits in with the theory of wing-tip air spill; it is also possible that these slots may be of use

to a partridge for control when he is using a high angle of incidence in gliding flight; but they are so very long that one can not help suspecting that their unusual shape is in some way connected with the characteristic fast-flapping flight of all game birds. In the wing of a partridge all six slots extend inwards for over one-third of the span of the wing, which may, therefore, be considered as consisting of two sections, the slotted and the solid. The question is, "How does the slotted section behave under the conditions of the extremely rapid beat of these birds?"

Before attempting to answer that question, it is necessary to run quickly through the action of a wing in simple, straightforward, flapping flight. The most important thing to remember is that the

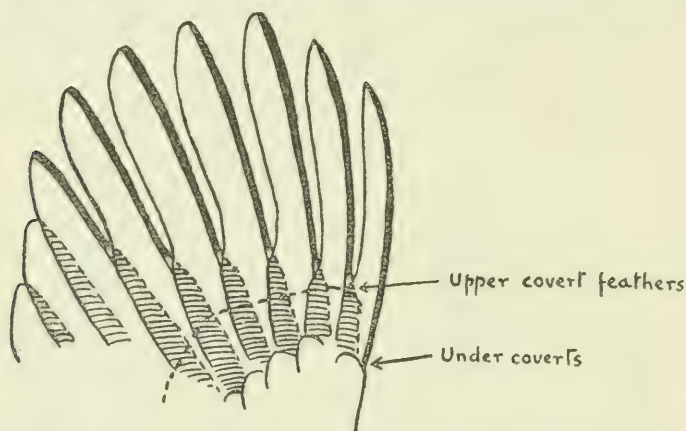


FIGURE 32.—Under surface of a partridge's right wing-tip. The un-emarginated parts of the feathers are shaded where they overlap

force produced by the reaction of displaced air must act, for the most part, upwards to counteract gravity; but also in a slightly forward direction to overcome the comparatively weak force of the resistance of the air to the passage of the bird's body.

For the sake of argument, let us imagine a case in which the required direction of total reaction is 10° forward of the vertical. To obtain it, the blades of the wings must lie in a plane tilted 10° (approximately) forward of the horizontal. The inclination of that plane governs the direction in which the wings must move through the air, for the air stream created by their movement must strike them at a suitable angle of incidence. Suppose that this angle is 10° ; then the wings must move forward through the air on a path inclined at 20° below the horizontal, as shown in Figure 33. This gradient path is a combination of the forward movement of the bird through the air and the downward movement of the wings themselves.

During this down beat, the wings, having their bones much nearer the leading than the trailing edges, will automatically tend to turn their blades into line with the air stream; so all that a bird has to do to apply the 10° of incidence is to prevent his wings turning any further when they have reached that incidence.

So much for the down beat. With regard to the upstroke, it is only necessary to say here that, as a rule, no lifting or driving force is produced; instead, the wings are relaxed and allowed to streamline themselves so that they offer the minimum of resistance to the downward and backward gradient air stream which they must encounter while moving up. The subject of the detailed working of wings in different phases and forms of upstrokes is such a tre-

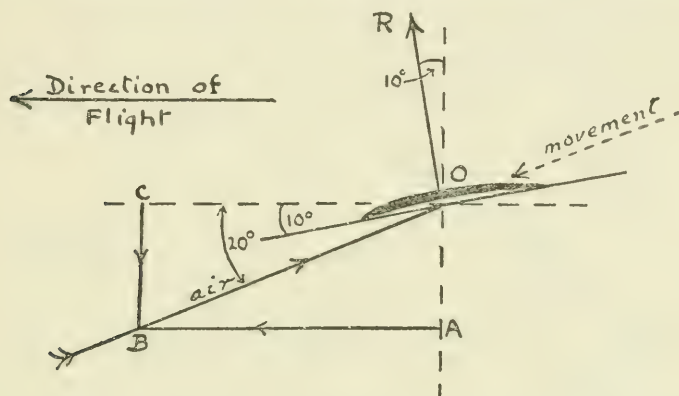


FIGURE 33.—The action of a section of wing in the down beat

OB, the path of the section through the air; CB and AB, the downward and forward movement of the section while it is travelling from O to B; R, the direction in which the resultant force acts.

mendous one that it could, like the question of the down beat, be made to fill a book by itself.

The action of the slot-forming feathers in the upstroke appears simply to be to join in with the others in effacing themselves as much as possible.

During a single down beat in straightforward flapping flight, all points on a wing move forward about the same distance, but the distance they move down varies a great deal, from approximately nothing at the shoulder to a maximum at the tip. Therefore the wing tip encounters a much steeper gradient air stream than the wing root, and to get the required incidence along the whole span, the wing itself must be twisted like the blade of a propeller. It seems probable that no incidence is given to the wing root and only a small amount at points inside the wrist; otherwise the reaction at those points would be directed backwards from the vertical—the

last thing that is wanted. That being so, the twisting would be reduced, but still a good deal would remain. That it does remain is borne out by photographs (fig. 34), and one can see it, by watching closely, with the naked eye.

The quicker the down beat, the steeper will be the gradient of the air stream encountered by points situated near the tip of a wing, unless the forward speed is correspondingly increased. Game birds, such as partridges, usually do fly at great speeds, but for the time being consider one that has not got up full speed. With its exceptionally quick beat, one would expect its wings to be very much twisted in the down beat, but in the few poor photographs which are obtainable of these birds in flight, there appears to be even less twisting of the wings than in slower-flapping birds; so one is led to suspect that the action of the slots is to allow the feathers that form them to twist individually. This is almost the same action as that of the wing-tip slots of a soaring bird, the main difference being that



FIGURE 34.—The down beat seen from behind showing the twist in the wings. Left, fantail pigeon; right, crane. (Sketched from photographs.)

practically the whole feather (except in the case of the rearmost slotted one) is free to twist, because the unemarginated overlapping parts are so short.

It appears then that each separate feather works away by itself, just like a little wing of a very high aspect ratio (long and narrow), giving the bird the double advantage of saving wing-tip air spill and weight; for a wing that could compete with the extreme twisting that an unslotted partridge's wing would require would have to be very strong indeed, and therefore heavy.

Figure 35 shows what a section of the wing taken halfway along the open slots might be expected to look like under these conditions. The pecked lines show the direction of the air flow between the feathers, and the arrows show the probable direction of the resultant force reacting on each feather. They remind one rather of a row of turbine blades.

This action of the slots in the down beat seems to be applicable to the flapping flight of all birds that have wing-tip slots, for the feathers can easily be seen to separate in each stroke; at any rate in such birds as rooks and crows. By careful watching it can even be

seen in faster-flapping birds, such as pigeons. It is quite probable that this "doing away with the need for the whole wing to twist" is one of the most important duties of wing-tip slots.

X. THE WRIST SLOT

In addition to the wing-tip slots already described, all birds are the fortunate possessors of another antistalling device which is even more like the Handley-Page gear. This is the alula or bastard wing.

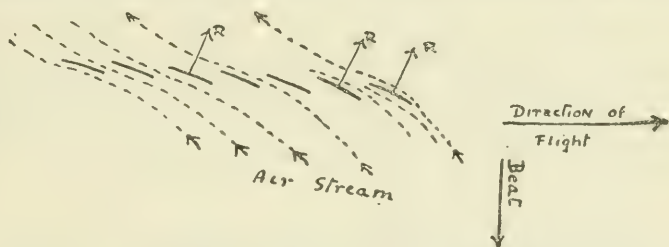


FIGURE 35.—Probable flow of air through the separated flight feathers of a partridge in the down-beat

It consists of one main feather overlaid by two or more auxiliary ones which give it strength and thickness. These all spring from a small limb which corresponds in the anatomy of a bird to the thumb of the human hand. In Figure 36 a wing is shown with all the feathers removed except those of the bastard wing and the primaries and secondaries. The relationship to a thumb is unmistakable.

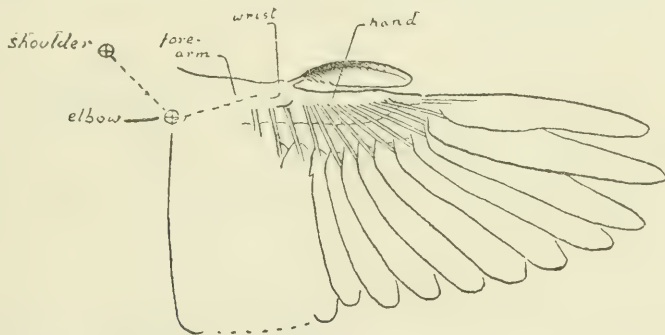


FIGURE 36.—Under surface of the left wing of a dove, with the covert feathers removed

This limb has a set of nerves and muscles all of its own. Headley, in *The Flight of Birds* (1912), remarks that it has more muscles than one would expect to be at the service of so insignificant a piece of machinery. Nowadays (1930) we know that it is not so insignificant, except perhaps in size.

Shufeldt, in his *Myology of the Raven*, says that the muscles and tendons that serve the bastard wing are so arranged that when the

main wing is fully spread the feathers of this tiny winglet are also spread so that they present the greatest amount of superficial area to the atmosphere; that is, they are ready for action.

When the main wing is at a fairly small angle of incidence, and there is no risk of a stall, the bastard wing serves no active purpose. It is so shaped that it forms part of the leading edge and therefore, with that part of the wing, is subject to pressure from the air stream. This pressure keeps it in position, and it does nothing more than fill in the slight "reentrant curve" in the leading edge of the main wing which can be seen in Figure 36.

When a wing is at normal angles of incidence, the area of pressure on the leading edge covers the whole breadth of the bastard wing, but as the incidence is increased the area of suction moves forward and sucks the bastard wing upward.

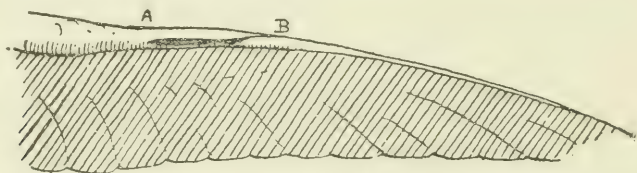


FIGURE 37.—Left wing of a woodcock seen from below and in front, showing the bastard wing in the "slot-closed" position. A-B, total length of the bastard wing

This may seem to be rather an astonishing statement, but it should be borne in mind that the air which passes over the top of a wing can not exert any upward suction until it has passed over the summit of the curve, or camber.

The upward force which the suction exerts may perhaps be added to by muscular action in accordance with Headley's observation, and may also be augmented by that part of the air stream which passes under the leading edge of the main wing, for there is a little pocket formed between the front of the bastard wing and the "reentrant curve" mentioned above into which air must press with increasing force as the angle of incidence gets greater. In Figure 37 this pocket is shaded black. But one thing seems certain, and that is that the opening of the wrist slot is mainly automatic and that it is brought about in the same way as the opening of a Handley-Page slot.

Once the initial upward movement has started, a stream of air passes between the main and bastard wings and assists the suction in its work by pressure from beneath. Having formed part of the curved-down leading edge of the main wing, the bastard wing, when acting on its own, finds itself to have a considerably smaller angle of incidence than its parent (fig. 38), therefore it remains effective and unstalled when the main wing has passed the stalling angle.

Another result of its smaller incidence is that the force reacting approximately at right angles to its surface is directed more forward than that on the main wing. Consequently, it is dragged forward as well as upward, like the separated feathers which form wing-tip slots. Further, the angle at which the pivot of the joint is set allows of motion more easily in that direction than in any other. The upward and forward displacement can be clearly seen in Figure 6. The right wing of the marsh harrier provides a plan view which shows the forward movement, and the left wing an elevation which shows the upward movement.

Nearly all bastard wings are curved down not only from front to back, but also from root to tip, so that when they are in the open position and the curve has been slightly reduced by the upward force of air reaction, they lie nearly parallel with the leading edge of the

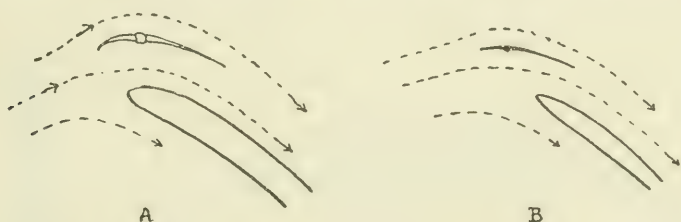


FIGURE 38.—Probable flow of the air stream through the wrist slot of a blackcock. A, near the root of the bastard wing and B, near the tip

main wing and are to all intents and purposes in the same position with regard to it as the auxiliary airfoil of an airplane wing which is fitted with the Handley-Page device; that is, displaced to a position parallel with, above, and in front of it.

Their action when in that position must be very much the same as that of the separated tip of the first flight feather of a single-slot wing described on page 280, in other words, to form an automatic safety device to prevent stalling when a large angle of incidence has to be used.

The action of the closing of the slot formed by the bastard wing must be just the reverse of the opening action. Put shortly, it may be said that as the incidence of the main wing diminishes toward the angle at which the assistance of an auxiliary to prevent stalling is no longer required, the incidence of the bastard wing being already less than that of the main wing, approaches the angle of "no lift," and finally it experiences a downward reaction which forces it down into its "stowed position" in the reentrant curve.

It is possible that the tiny "flexor" muscle (*flexor brevis pollicis*), which is so arranged that it pulls downward on the bastard wing, assists air pressure in this process, and it is also possible that the

"extensor" muscles, which are designed to pull upward on it, come into play in the opening process more than has been suggested; but the most likely duty of these muscles is to damp down the movements of the bastard wing and "steady" it in the closed or open position, just as the springs of the Handley-Page slotted wing device do. Shufeldt says of the "flexor" muscle that it is sufficiently powerful to retain the bastard wing in the closed position when the wing is folded.

The considerations which govern the length of the bastard wing in different types of birds form a most interesting study. Like the wing-tip slot, this other form seems to be influenced chiefly by the aspect ratio, for birds with long, narrow, pointed wings, like the sea birds, and such birds as the golden plover and woodcock, have smaller bastard wings than the short-winged types, such as the game

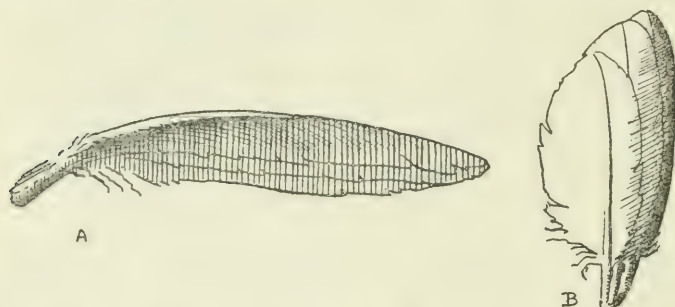


FIGURE 39.—Bastard wing of a blackcock. A, seen from below and in front; B, from above, slightly foreshortened

birds; though, again, such matters as wing loading, size of bird, speed of flap, span loading (weight carried per unit of length between wing tips)¹¹ and habits of living may have a certain influence as well. Figure 40 and the left-hand bird in Figure 41 show examples of the bastard wing in action, and the right-hand bird shows the appearance of a wing when the slot is closed.

It would be rash to come to any conclusions as to the lessons that are to be learned from the antistalling devices of birds without careful consideration of the influence that flapping flight may have upon their design; but two things seem to stand out clearly: (1) That the ideal glider is one that has great span, high aspect ratio, and pointed wing tips, like an albatross, and (2) that such a glider would probably be but little improved by the presence of any form of anti-stalling device, either on the main wing or on the control surfaces. But if practical considerations, such as structure weight, housing, and handiness for operation, dictate a smaller span, then it is worth while

¹¹ Data on these matters will be found in the table.

considering the fitting of some form of aid to control and lift. As all airplanes are, in effect, gliders with motors in the place of gravity to give them forward movement, the same thing should apply to them as well.

SUMMARY

The connections between the ways of birds in the air, their size, the shape and loading of their wings, the presence or absence of slots, and, when present, their development, are so intricate that many years of investigation would be required before really satisfactory conclusions could be reached. The surface of the subject has only been scratched in this paper, but it is hoped that the scratches will have indicated the amazing width of this field for research and the possibility of the riches that may be found in it. For what they are worth, the observations, theories and tentative conclusions which have been mentioned are summarized below.

1. Wing-tip slots are formed by the gaps left between the emarginated tips of the flight feathers of a fully spread wing.

2. They vary in number, if present at all, from one to eight, and in size from nearly half the length of a wing to mere vestiges.

3. Their presence appears to depend primarily on the proportionate length of the wings of a bird and on the shape of their tips. Short wings, with rounded or square tips, have the greatest number and the highest development of these slots. Long, narrow, pointed wings have none.

4. By doing away with mutual support between feathers, slots form an automatic antistalling device, which appears to work in somewhat the same way as the Handley-Page slotted airplane wing.

5. Wing-tip slots increase lateral control at low air speeds.

6. They reduce the losses in efficiency of a wing that are due to the spilling of air over the tip.

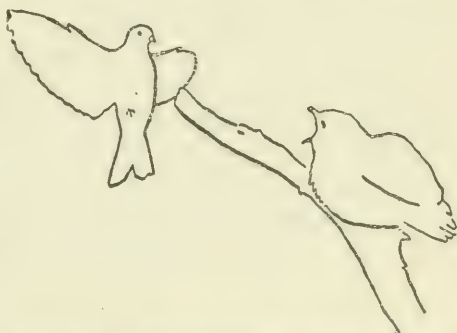


FIGURE 40.—Meadow-pipit about to alight to feed a young cuckoo. The wrist-slots are open. (Sketched from a photograph)

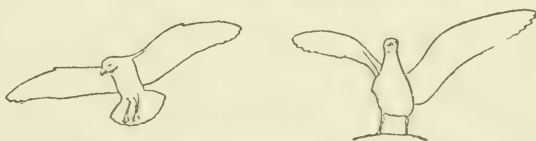


FIGURE 41.—Great black-backed gull; on left, with the wrist-slots open and, on the right, closed. (Sketched from photographs.)

7. They reduce the amount of twisting that is required in flapping flight to align the outer parts of a wing reasonably near the gradient of the air stream, which is much steeper at the tip than near the shoulder.

8. The final spreading of a wing, which opens the slots, appears to be done automatically, air reaction dragging the separated feathers forward when the incidence is sufficiently high.

9. Overspreading of a wing, to the extent that gaps would appear between the feathers on the body side of the inner extremities of the slots, is prevented by means of special friction surfaces on the overlapping parts of the feathers.

10. The wings of all birds found in the British Isles possess a second antistalling device situated just outside the wrist joint, in the shape of the bastard wing. Its size varies in different species from about one-tenth of the length of the wing to about three-tenths. In form, action, and effect, it more closely resembles the Handley-Page auxiliary airfoil than wing-tip slots do.

Some flight characteristics

	Weight (ounces)	Wing loading (pounds per square foot)	Span loading (ounces per foot)	Span (inches)	Aspect ratio	Wing- tip slot factor	Wrist- slot fac- tor	Number of wing- tip slots
Long-tailed tit.....	0.25	0.26	0.46	6.50	1.85	1.46	0.15	6
Wren fledgling.....	.31	.47	.79	4.70	1.70	.77	.24	3
Coal tit.....	.33	.39	.57	6.90	2.20	1.00	.13	4
Wren (adult).....	.36	.40	.92	4.70	1.70	.67	.18	3
Blue tit.....	.37	.33	.60	7.40	2.20	1.10	.16	5
Marsh tit.....	.38	.36	.60	7.60	2.00	.98	.17	5
Goldfinch.....	.44	.36	.69	7.70	2.35	.54	.15	3
Robin.....	.50	.39	.71	8.40	1.94	.82	.18	4
Swallow (fledgling).....	.56	.35	.66	10.25	2.95	-----	.17	-----
Spotted flycatcher.....	.56	.35	.69	9.70	2.45	.17	.16	3
Gray wagtail.....	.56	.44	.70	9.60	2.27	.45	.16	3
Great tit.....	.69	.49	.97	8.50	1.68	1.36	.20	6
Wheatear.....	.72	.36	.86	10.00	2.20	.84	.15	3
Blackcap.....	.75	.62	1.10	8.00	2.30	.42	.17	3
Linnet.....	.75	.54	1.00	9.00	2.32	.45	.16	3
House sparrow (hen).....	.75	.43	1.10	8.00	2.50	.45	.16	3
Pied wagtail.....	.75	.41	.85	10.60	2.37	.47	.18	3
Reed bunting.....	.75	.43	.95	9.50	2.05	.76	.16	4
Swallow (adult).....	.81	.34	.80	12.50	3.50	-----	.13	-----
Hedge sparrow.....	.81	.67	1.22	8.00	1.75	.69	.18	4
Yellow hammer.....	.87	.56	1.04	10.00	2.20	.75	.17	4
Bullfinch (hen).....	.87	.53	1.16	9.00	2.05	.36	.19	4
Chaffinch (hen).....	.87	.54	1.10	9.60	2.30	.73	.18	4
House sparrow (cock).....	1.00	.58	1.18	10.20	2.30	.58	.17	3
Green-finch.....	1.12	.55	1.25	10.75	2.50	.62	.17	4
Wryneck.....	1.37	.68	1.37	12.00	2.80	.18	.12	1
Skylark.....	1.50	.50	1.40	13.00	2.60	.60	.16	3
Jack snipe.....	2.00	.93	1.70	14.20	3.30	-----	.16	-----
Song thrush.....	2.31	.77	2.00	13.80	2.46	.55	1.17	3
Nightjar.....	2.31	.40	1.30	21.50	3.40	.36	.16	2
Hoopoe.....	2.50	.55	1.66	18.00	2.06	1.00	.16	3
Starling.....	2.50	.75	2.00	15.00	2.90	.21	.16	2
Golden plover.....	3.00	1.18	2.10	17.00	3.60	-----	.12	-----
Blackbird (hen).....	3.50	.87	2.90	14.50	2.10	.70	.20	4
Quail.....	4.00	1.76	3.20	15.00	3.17	.18	.20	1
Common snipe.....	4.00	1.23	2.75	17.50	3.78	-----	.16	-----
Sparrow hawk (hen).....	4.00	.45	2.00	24.00	2.65	1.22	.27	5
Scops owl.....	4.25	.64	2.38	21.40	2.36	.31	.20	2
Mistle thrush.....	4.25	1.05	3.10	16.50	2.40	.72	.18	4

¹ The wrist-slot factor of a young song thrush on its first day out of the nest was found to be 0.3.

Some flight characteristics—Continued

	Weight (ounces)	Wing loading (pounds per square foot)	Span loading (ounces per foot)	Span (inches)	Aspect ratio	Wing- tip slot factor	Wrist- slot fac- tor	Number of wing- tip slots
Little owl.....	6.00	1.02	3.67	19.60	2.40	.68	.19	4
Jay.....	6.00	1.03	3.52	20.50	1.90	1.42	.17	7
Lapwing.....	6.50	.57	2.90	27.00	2.80	.39	.14	3
Black-headed gull.....	7.00	.63	2.47	34.00	4.60	-----	.11	-----
Kestrel.....	7.75	.96	3.72	25.00	3.30	.22	.19	2
Partridge.....	12.00	2.00	8.50	17.00	2.33	1.70	.22	6
Chough.....	12.00	.76	4.64	31.00	2.25	1.30	.18	5
Moorhen.....	12.00	1.43	6.75	21.30	2.70	-----	.26	-----
Domestic pigeon.....	12.00	.95	5.00	28.50	2.80	.53	.19	3
Woodcock.....	12.00	1.24	6.00	24.00	3.00	-----	.13	-----
Teal (cock).....	13.00	1.96	6.40	23.50	3.60	.11	.16	1
Common gull.....	16.00	.85	4.50	43.00	5.23	-----	.12	-----
Red-legged partridge.....	16.00	2.50	10.00	19.00	2.17	.86	.30	5
Rook.....	16.00	.98	6.30	30.40	2.43	1.10	.20	5
Short-eared owl.....	16.00	.76	4.80	39.50	3.25	.08	.13	2
Wood pigeon.....	18.00	1.48	8.00	27.00	2.62	.39	.17	3
Showeller duck.....	20.00	2.50	8.00	30.00	4.30	.13	.17	1
E. little bustard.....	22.00	1.46	7.70	34.50	2.95	1.20	.15	5
Grouse.....	23.00	2.23	11.50	24.00	2.67	1.60	.22	5
Great crested grebe.....	24.00	3.50	9.60	30.00	4.20	.11	.15	2
Curlew.....	29.00	2.00	9.20	38.00	4.10	-----	.12	-----
Willow grouse.....	30.00	2.85	13.30	27.00	2.25	1.30	.27	5
Pheasant (cock).....	38.00	2.40	19.00	24.00	1.70	2.80	.27	8
Heron.....	40.00	.92	9.10	58.00	3.00	.33	.12	3
Blackcock.....	40.00	2.56	15.40	31.00	2.46	2.00	.24	6
Griffon vulture.....	260.00	1.85	31.00	94.00	2.72	1.40	.14	8

COLUMN 1.—Gives the approximate weight in ounces.

COLUMN 2.—The wing loading is given in pounds of weight carried per square foot of wing area. The area is taken to be the greatest projection of the 2 wings spread with their tips at right angles to the body.

COLUMN 3.—Gives the weight in ounces carried per foot span of the wings. These units were chosen as giving figures of convenient size for drawing graphs. The span is taken to be the distance between the wing tips when spread as for measuring area.

COLUMN 5.—The aspect ratio (or ratio of fineness) is arrived at by dividing the distance between wing tip and body by the mean breadth. The mean breadth is obtained by taking 7 measurements along the direction of flight, at points situated $\frac{1}{8}$, $\frac{3}{8}$, etc., of the length of the wing measured inwards from the tip.

COLUMN 6.—Gives the total length of slot that opens between separating feathers in 1 wing, as a fraction of the length of the wing measured from tip to body. The length of any 1 slot has been taken to be the length of the shorter margin of the slot when it is fully open.

COLUMN 7.—Gives the length of the bastard wing as a fraction of the length of the wing. As it is difficult to determine how much of this winglet is actually operative, owing to some of it being blanked off by small feathers near the root, the measurement has, in all cases, been taken by sliding a ruler under it and pressing in toward the wing root as far as possible.

The figures given above are only intended to give a rough idea of how the data vary with different types of birds and different methods of flying. They should not be considered as accurate, because they do not represent averages taken from a large number of birds, and because accuracy in measurement of these things is well-nigh impossible.

THROUGH FOREST AND JUNGLE IN KASHMIR AND OTHER PARTS OF NORTH INDIA

By CASEY A. WOOD

[With 2 plates]

The man in whom that uneasy affection Wanderlust has developed must feel a thrill if, without warning, he comes across Richard Hovey's Sea Gypsy. Its call is even more alluring than Kipling's Road to Mandalay, and it might be read as a prelude to that immortal poem:

I am fevered with the sunset,
I am fretful with the bay,
For the wander-thirst is on me
And my soul is in Cathay.

There's a schooner in the offing,
With her topsails shot with fire,
And my heart has gone aboard her
For the Islands of Desire.

I must forth again tomorrow!
With the sunset I must be
Hull-down on the trail of rapture
In the wonder of the sea.

In any event, I may be pardoned for quoting it as an introduction to some of the wonderful natural beauties that one encounters in the far-off jungle lands that border on central Asia.

If one were to draw a line (over 1,600 miles long) from Kabul in Afghanistan to and along the southern frontier of Bhutan and another one following the northern aspects of the Himalayas from the western outlet of the Khyber Pass to the upper border of Bhutan, it would inclose an irregularly curved parallelogram that frames one of the most important physical and historical areas in the wide world. At intervals during many centuries there migrated, by way of wild passes that double and twist their sinuous paths over the mightiest of mountain ranges, peoples of many northern types who fought their way into the fertile plains of Hindustan. Greeks, Persians, Afghans, Parthians, and many minor tribes contended for the mastery of the industrious but less warlike inhabitants of north and middle India. As the tides of invasion ebbed and flowed the

conquerors of the day left their imprint to some extent upon the physiography of the land. Occasionally they cut down forests, partially to replant them, in part to restore them as gardens, orchards, shady walks, and leafy avenues. Moreover, though they rarely built a road through a forest or over a mountain that compared with the highways characteristic of Roman constructions, yet all over northern India are indications that they made mountain and jungle roads sufficient for the needs of transportation.

The historic Khyber Pass is, of course, the best known of the gateways through the Himalayan region, and when I passed over it in 1926 and looked for some remnant of the extensive forest that probably clothed both sides of the rugged valley along which Alexander the Great and Kublai Khan led their disciplined hosts nearly 1,500 years ago, I looked in vain. Here and there a scrubby tree, a solitary pine, or a clump of herbaceous shrubs showed their struggling heads above the rocks, but otherwise the landscape consisted of rocks, rocks, rocks, bathed in the hot sunshine. No wonder the Afridis, Pathans, and other hill tribes are and were forced to forego husbandry, forestry, and agriculture and to live mainly by internecine warfare, robbery, and murder. Somebody has said the people who do not raise cattle or cereals generally raise hell!

Farther east and south, but still within this northern parallelogram, the scene changes. We find that the nearer we approach Nepal and the eastern Himalayas the more liberally clothed in tangles of jungle and evergreen forest are the mountain sides.

The derivation of the word Himalaya is both poetic and appropriate. *Him* is the Sanskrit for snow and *alaya* means abode; hence "home of the snow." Geographically and roughly this magnificent mountain range may be described as that elevated area between Thibet and India fenced in by the rivers Indus and Brahmaputra. The sides of the many valleys that crisscross the plateaus of these lofty mountains are generally very steep. The gorges and canyons have not been filled by the rivers and creeks that slowly carry the detritus of the hills to a resting place in the lower levels. There are, however, some exceptions to the rule, one of which is the lovely Vale of Kashmir about whose natural history it is my purpose later to speak. The alluvial debris carried by the river Jhelum meets a rocky strait near Baramulla and instead of being borne along swift currents to empty into the Ganges it is deposited at the foothills to form that fertile basin whose praises have been sung for so many generations.

If I were asked to say what section of north India affords the best opportunity for a study of the denizens of this montane bushland I would be inclined to choose Kashmir. On the other hand, such are

the attractions of almost every elevated terrain of the Himalayan Range that it is difficult to make a selection. Perhaps my choice of Kashmir and its surroundings is influenced by a happy spring and summer spent in that terrestrial paradise. From our house boat on the Jhelum we made excursions into the higher mountains, to Gulmarg and toward Thibet, then across the Indus into Afghanistan and to other localities.

Owing chiefly to the higher latitude, greater elevation, and distance from the ocean, the flora of the valleys and plains that stretch along the southern aspect of the Himalayas is less decidedly tropical. The humidity is less and the lowered temperatures of the cold months are more marked. Kashmir, for example, has a "real winter" with plenty of snow and ice, spring rarely appearing before the end of April. The summers are hot and the small European population generally moves to higher levels during July and August.

The dominant factor in plant life everywhere is elevation. At the higher levels of the Indian hills many floral species are found identical with those of the British Isles; in the Alpine areas there are varieties very similar to those of the Arctic Zone, while certain flora found throughout Japan, China, and Siberia is more or less abundant; for example, the rhododendrons, the tea plant, *Adamia*, and numerous others, although I have never noted a number of well-known European and Asiatic plants, such as wild azaleas, arbutus, or *Erica*. However, the flora of the Himalayan Range very largely includes that of both central and southern India.

To my mind the most wonderful form of plant life in the Himalayas is its silva. In the eastern sections the mountains are practically covered by dense forests up to 13,000 feet, and some tropical examples are found as high as 7,000 or 8,000 feet. The western ranges are not so liberally supplied; the upper limit of forest and jungle is somewhat less, about 11,000 feet, tropical types disappearing at 4,000 or 5,000 feet.

From this brief outline it may be gathered that the Himalayan chain with its foothills, valleys, and river bottoms furnishes the botanist with an almost complete repertory not only of the great majority of Indian plant life but of illustrations of the principal floral families of the entire world. On the other hand, the region has very few indigenous species—few plants with characters all its own. Sir Thomas Holdich calculates the number of flowering species to be between 5,000 and 6,000, among them several hundred common English plants chiefly from the Alpine and temperate regions.

The yield of the forests of Kashmir is of great value. All the northward-facing slopes are covered with dense forests, a consider-

able part of which is of the valuable deodar. This is cut into lengths, launched into the streams which find their way into the Jhelum, thence to float down the river to the plains of the Punjab. Here the logs are caught, where the river is slow and shallow, and sold at considerable profit to the State. The deodar is a very handsome tree, and is a variety of the cedar of Lebanon. It will be noticed by visitors to the valley along the road between Uri and Baramulla, especially near Rampur. Less beautiful and less valuable as timber is the blue pine (*Pinus excelsa*). It grows at a greater height than the deodar, which does not flourish over 6,000 feet, and it may be seen at Gulmarg. The Himalayan spruce (*Picea morinda*) is very common, and also grows around Gulmarg, but its timber is of little value. Birches grow high up above the pines and next the snows; their timber is of no use, but the bark is much employed for roofing. In the forests are also found silver fir, horse chestnut, and maple.

Another tree, a native of North India, is the mulberry (*Morus indica*). This species is a valuable source of income chiefly because of the food the leaves furnish the silkworm. The fruit resembles a small red peppercorn, and such of it as escapes the birds furnishes the native with material for pleasant stews and tarts. The States of Kashmir and Jammu distribute (under certain conditions) to native cultivators of this indigenous tree supplies of the eggs of the silkworm, whose cocoons are in turn sold to the silk factories. In Mohammedan Kashmir there is no objection to the necessary destruction of the moth living in the center of his cocoon, and the industry flourishes, but in Buddhist India and Ceylon this act is regarded as a serious religious offense, and it strongly militates against the commercial success of the enterprise in certain parts of those countries.

All the forests are owned by the State and are under the charge of a forest department, often with a conservator from the Government service at its head. The boundaries of forests are laid down and the State determines under what conditions neighboring villagers and others may be granted the customary concessions for felling timber, grazing, and gathering grass and fuel. It is usual for the State to let fuel and fodder be gathered free and to charge for grazing and for cutting timber for building and agricultural purposes. The trees are counted, marked for felling according to their age, and in regular succession, so as to allow of young trees growing up to fill their places. In many other ways the forests are watched so as to prevent their denudation, as well as to avoid the damage that would be caused through the rainfall rushing off at once instead of being held up by the trees.

By this regulation of the forests the State raises a handsome income; it insures the soil being retained on the hillsides, and it has

the water held up in springs as a reservoir. The authorities in the Punjab also know that the rain which falls in Kashmir will be held up by the forests till the cold weather, when it is wanted for the canals which are taken off from the Jhelum and Chenab Rivers flowing out of Kashmir territory.

Of the trees that flourish in the level portions of the valley, the chenar is by far the most striking. As it grows in Kashmir it is a king among trees, and its autumn foliage is one of the many attractions which go to make Kashmir one of the supremely beautiful spots in the world. Its botanical name is *Platanus orientalis*, one of the varieties of the plane tree. The chief characteristic is the massiveness of its foliage. It grows to a considerable height and has long outstanding branches and great girth. One that Lawrence measured was 63 feet around the base. As the leaves, that remotely resemble those of our sugar maple, are broad and flat, the whole mass of foliage is immense and so thick that both sun and rain are practically excluded from anyone sitting under it. Under the chenar trees in the residency garden at Srinagar one can sit through a hot summer day without a hat and through a summer shower without getting wet. All this mass of foliage turned purple, claret, red, and yellow in the autumn tinting, backed against a clear blue sky and overhanging the glittering, placid waters of the Dal Lake or the Jhelum River, forms a picture which can be seen in no other country.

The elm tree of Kashmir, though not so striking as the chenar, is still a very graceful object. One in the Lolab Valley has been measured as 43 feet in girth, and in the residency garden at Srinagar are some fine specimens. The walnut is more common, and around the villages many handsome examples of this tree are seen. The poplar is now very common, and is planted alongside the road to what is to the tourist quite a distressing extent, for though these trees furnish desirable shade they also cut off the view. The timber is used a good deal for building, though it is of poor quality. The willow is a more useful tree and is much planted in moist places. Its leaves are used for fodder and its shoots are to some extent employed for basket making.

Of the many herbaceous forms that delight the eye in the Himalayan region perhaps that gorgeous lily, *Gloriosa superba*, is the most curious and attractive. Other plants and shrubby vegetation are chiefly representatives of European and Asiatic growths. One may see on the foothills and in the unexposed interiors almost identical examples of such well-known plants as clematis, gentian, primula, saxifrage, geranium, potentilla, and berberis, while species of holly, birch, alder, maple, elm, ash, walnut, yew, horse chestnut, as well as many coniferae and junipers, are well represented.

In Kashmir a number of introduced silvan species flourish. Prominent features of the landscape are long and healthy avenues of Lombardy poplars planted, as windbreaks, and sources of local timber, through the influence of British officials. These trees are numbered and carefully protected from local thieves whose easy morals do not prohibit the destruction of a tree "when nobody is looking."

The cherry and the plane tree, tea, and cinchona are other successful immigrants, giving certain parts of the country a distinctly European cast. In the high mountains, however, the Kashmir flora is that of Persia, Afghanistan, and Siberia. Finally, although there is a native coffee plant growing in the hotter parts of the Himalayas, climatic influences do not favor the growth of commercial species.

Many of the Himalayan silva are noted for their beautiful blooms, for their peculiar fruit, their flaming leafage or the eccentric forms of trunk or branches. One notices not only these, but also rare rhododendrons, magnolias, daphnes, laurels, nutmegs, cherries, roses, viburnum, pandanus, bombax tree ferns, bamboos, etc., some of them adorned with orchids and other epiphytic plants. Among the last-named is the calamus, climbing over even the tallest trees.

As Holdich points out, rhododendrons begin at 6,000 feet, become abundant at 10,000 to 14,000 feet, and form in some instances masses of shrubs 2,000 feet above the forest line. Orchids are very numerous, especially between 6,000 and 8,000 feet.

As Sir Thomas Holdich also indicates, the distribution of animal life of the Himalayan region results from about the same factors that determine the character of its botanic forms. The connection of north India with surrounding countries and continents is doubtless responsible for the large number of modern European and far eastern species and for many corresponding prehistoric forms.

A well-known animal characteristic of the Thibetan highlands is the yak (*Bos grunniens*), that dark brown, long-haired ox, weighing often 1,000 pounds, that when domesticated proves as valuable to the people of central Asia as our own buffalo was to the North American Indian. It must be remembered that a still more useful animal is a cross between the yak and the horned cattle of Hindustan. The Himalayan region furnishes also numerous wild sheep, the musk deer, wild asses, ermine, antelopes, and many other animals.

Unless one has visited and picnicked in them it is difficult to realize the picturesque beauty of the gardens planted by the Moslem emperors of India and their wives. A love of landscape decoration was an outstanding virtue of the Persian conquerors of north India, who were quick to see and eager to take advantage of the many beautiful settings for landscaping on a grand scale, including

that glorious combination of verdure covered mountain, valley, lake, and river that constitutes charming Kashmir. Of the larger gardens laid out by them in the neighborhood of Srinigar the most famous is the Shalimar, a few pictures of which my camera vainly attempts to portray. Artificial and highly ornamental canals supply water for irrigating purposes and for the fountains, whose sprays and rills still dot the landscape and add their coolness to the surrounding air. Of the kiosks that remain after a lapse of three centuries and that still adorn the Shalimar, the beautiful colonnaded, marble pavilion of Shah Jahan is the most noticeable. Fed by an aqueduct that in imperial days brought an abundant supply of water to the gardens, this architectural gem is the center of attraction in this lovely garden.

The Shalimar is the chief holiday resort of the Kashmiri living in the capital city, some 3 miles distant. Here one meets a decorous, merrymaking crowd who, arriving in boats on the Dal Lake as well as by bullock cart and on foot over a picturesque highway, bring their food and picnic the happy, lifelong day.

We had the unusual opportunity of being guests of the present maharajah when he celebrated in these gardens his accession to the throne of Jammu and Kashmir. He invited to this celebration several of the neighboring chiefs, their wives, and attendants, all of whom were housed in gorgeous tents whose floors were covered with priceless carpets and rugs. The few Europeans, officials in particular, turned out in their best. But who could compete with the multi-colored silks, turbans, and flashing jewels of the native chieftains and their entourage?

Drinks of all kinds (except the alcoholic), sweetmeats, and cakes were passed to the guests, and in surroundings of natural and artificial splendor, which we never hope to see again, an unforgettable afternoon was passed. On the way home in the summer evening the boatmen of our gaily curtained shikara, still under the influence of the lively scenes we had just left and to the accompaniment of many curious instruments played by musicians in our own and hundreds of other boats, sang as we paddled along. The gardens of Dal Lake certainly deserve to be classed among the prime attractions of north India.

During my residence in Kashmir, I had distant views of one of the largest birds in the world, the Himalayan bearded vulture (*Gypaetus barbatus hemachalanus* Hutton), sailing slowly along the high mountain sides toward Little Thibet. I have also had several opportunities of discussing the habits of this wonderful bird with naturalists who had succeeded in securing specimens. One of these, a friend who lives in Agra during the winter and in Simla during the sum-

mer, promised to send me a skin or two. There is much confusion in the minds of amateurs regarding this bird, some believing the European lammergeier (*Gypaetus barbatus grandis* Storr) to be identical with the north Indian species. There are, however, several distinct varieties of this remarkable bird of prey, the Kirke Swann monograph (*Accipitres*) recognizing five good species. This is not the proper place to stress the point, but the so-called Swiss bird is the species best known to tourists and readers of popular zoological works. Unfortunately, however, this magnificent bird is no longer to be found in its former Alpine haunts, but is confined to the higher mountains of Spain, to the Balkans, and to a few of the Mediterranean coast ranges. A few examples also survive in Asia Minor and Persia.

Stories of the Alpine lammergeier (or of any other vulture) carrying off live goats, chamois, or young children are without foundation. Despite its name, it is doubtful whether it has been known to molest even a (healthy) lamb.

Round about Simla the residents speak of this bird as the "golden eagle." Both Hutton and Hodgson say that its food is usually carrion, sometimes the smaller mammals, and reptiles; it rarely carries off anything alive larger than a fowl, which it devours while on the wing. In spite of the fact that the "eagle" is really a vulture it presents a noble appearance, with its immense spread of wing as it "quarters" the hill tops, floating along in noiseless flight searching for food, keeping a few feet from the tree tops or ground until it has beaten the chosen area from top to bottom.

Comparatively few monkeys are found in the mountain jungles of north India. The Himalayan langur (*Semnopithecus schistaceus*) is a long-tailed species living in the cooler elevated regions. It is of a grayish color and sports bushy eyebrows and a chin tuft. It is unusually active and exhibits wonderful leaping powers.

Innumerable are the stories told about this highly intelligent and well-known monkey. Among them is the account given by Mrs. H. C. Eggar in her *An Indian Garden*.

A pair of great brown Langours, living in the jungle, come every day along the garden wall, swinging themselves up into the topmost branches of the best mango tree, where they sit defying everybody, breaking off the choicest fruit and eating it before our eyes. The dogs nearly choke themselves with wrath, and so do we, standing underneath. Jogee and Poonia and their men hurl stones and abuse at them, none of which affects them in the least. The largest one is about 5 feet high, if standing straight upright, and he sat there in the tree last week, calmly munching his mangoes and throwing us down the large seeds, caring not a pin for Jogee. When a stone came rather near him, he watched it and ducked his head; then changed his position, crossing one leg over the other comfortably, and continued eating. He treated me with the same contempt, though I waved a large white umbrella at him, frantically

jerking it up and down as high as I could reach. A Langour, upcountry, once took up a terrior and tore it in two, and another ran off with a native baby. When the crowd pursued him, he rapped the child's head on the ground and killed it, so vicious are they. I hoped these monkeys would disappear when there were no more mangoes to steal, but now they come for the guavas. So we are obliged to gather them before they are ripe.

To this tale should be added that in India the monkey is a sacred animal which seriously to injure or to kill is an offense against law and religion.

I saw a number of bats, but nothing out of the ordinary except perhaps the interesting fruit bats, of which I shall speak later. Bears are quite common, as are wildcats and wild dogs, while in the lower valleys leopards and tigers are permanent residents. The mongoose and the civet cat (and other smaller *Felidae*) are quite commonly seen, but there are no forest wolves nor foxes. *Aclurus*, a peculiar animal called the "cat bear," closely resembling our American racoon, is found here, as well as an aberrant badger and the familiar flying squirrel. The elephant is now found only in the outer north Indian forests as far as the Jumna, and the rhinoceros as far as the Sarda—receding limits within historical times. The habitat of these familiar beasts once extended to the Indian plains, but modern firearms have been the cause of their contracted area. Deer, wild pigs, including a pygmy species (*Sus silvanus*), as well as several goatlike mammals, abound in various localities.

I always associate that remarkable fruit bat, *Pteropus edulis*, the flying fox, that one sees in flocks sometimes numbering thousands all over India and Ceylon, with another living object, the beautiful deodar (*Cedrus deodara*). These destructive *Chiroptera* roost (or hang upside down) from many other trees, but the small fruit of this "timber of the gods" seems to be especially attractive to all fruit bats. *Pteropus* certainly justifies his vernacular name. His extended wings measure often more than 3 feet, his body is covered with fine fur, and both head and body are shaped exactly like a small, dark-colored fox.

Almost every evening in any part of the country where there are fruit bats and this lovely cedar, parties of flying foxes seem to rise in the rays of the setting sun and take their flight with lazy but loud flappings of their wide membranous wings to settle in the trees. Natives who have lawful possession of a gun take pot shots at them, those that fall being used as food. I have eaten many kinds of "flora and fauna," but I never could bring myself to the mastication of fruit-bat flesh, although the Indians declare it tastes like chicken.

The domestication of the deodar in most countries has made it familiar to Americans. Indeed, I believe I have seen as fine examples

of this charming cedar in California as in India. In the semitropical States it preserves the year round its graceful habit and fresh green, modified from time to time by small flowers and ripening fruit—appearances to the delight of the passer-by—sweeping the ground with its branching foliage and affording shade and shelter to man, bird, and beast.

India is also famous for its flowering trees, and May is the month when most of their blooms can be seen at their best. The gardens and forests of north India have a full share of these silvan wonders, too numerous even to be mentioned here. I know a city garden where over a hundred flower-bearing varieties may be seen, together with such commonplace examples as date palms, figs, and mangoes. One also sees the jak (*Artocarpus integrifolia*) with its immense, elongated pumpkinlike gourds growing not only from all the branches but from the trunk, often weighing 30 pounds. Both the coarse albumen and malodorous seeds of this species are cooked and eaten by the natives. Then there is the peepul tree (*Ficus religiosa*) or bo tree, sacred to Buddha, one of which (in front of a Sinhalese temple in Anarajapura) is the oldest historical living object, having been planted there more than 2,000 years ago. This venerable tree is only exceeded in age by our California redwoods.

A fine example of tree blooms is yielded by the tulip or cork tree (*Millingtonia hortensis*) that flowers in the tropical winter. Its elmlike tops and surrounding branches are clothed by pure white, scented florets. Also covered with masses of white, sweet-smelling blossoms is the sacred neem tree (*Melia dubia*).

Perhaps the most attractive of all the flowering trees of north India is the *Brownia*. Twice a year it furnishes a massive crop of rhododendronlike, heavily perfumed, yellow and red blossoms. Not only are the spreading branches thickly loaded, but, wonderful to relate, through rents in the bark of the trunk appear magnificent blooms that may almost conceal the bole of the tree.

For some reason or other I failed to recognize near my Indian residence a good-sized *Gardenia florida*, often called the cape jasmin, of whose white flowers I am very fond. When I did wake to the fact of its presence, I also learned that one of my servants had daily robbed the tree of its bloom and sold me a buttonhole bouquet for a few annas. I am foolish enough to believe that the surprised pleasure of each transaction that I continued to express really meant more to him than the few pennies that were duly exchanged for these lovely flowers that would have sold for as many shillings on Bond Street.

One of the most interesting of the trees introduced into India and Ceylon from tropical America is the candle tree (*Parmentiera cer-*

eifera). It is a medium-sized, flowering species whose biennial blooms spring almost altogether from openings in the bark of the bole and branches, and give no indication of the remarkable fruit that is to follow. One barely notices the inconspicuous tree and its flowers, but later on is struck by the appearance on stem and branches of a profusion of yellow, juicy, candlelike fruit. Surely it can not be the same tree! The long, cylindrical fruit (see the illustration) bears a remarkable resemblance to the old-fashioned tallow candles of our forefathers. Little use is made of these natural "candles," except that in times of stress they are said to be eaten by the natives.

Speaking of "introduced" species of plants and animals, it is by no means easy to say how long flora and fauna must live and propagate their kind in a new land before they can claim a place among the citizens of the country into which they come as migrants. It is a matter of opinion. For example, among the Indian flowering trees are the *Brownias* (already mentioned) that dispute the title with *Amherstia* as the most beautiful blossoming trees in the world, yet the members of the former genus were originally South American. The most attractive of them all and the one that I know best is *B. grandiceps*, the rose of Venezuela, that reaches a height of 40 feet. When in full bloom this tree is one blaze of glory from bunches of bright red flowers borne in large, dense heads at the extremities of the branches. As in the case of *Amherstia*, the foliage is also very conspicuous. The young mottled leaves are grown as long flaccid bunches, giving the tree the appearance of bearing two dissimilar sets of flowers.

One of the most striking and showy of eastern silva is the so-called pride of India or queen's flower (*Lagerstroemia flos-reginae*), named after the East Indian botanist Magnus van Lagerstroem. It is found all over India, Ceylon, and Malaya and from April to October bears from the ends of its branches erect panicles of lovely bright pink or mauve blooms. With the exception of a short time during the rainless season these beautiful trees retain their green foliage. The margin of the pretty Kandy Lake in Ceylon is brightened by many flowering trees, but none more attractive than this magnificent species.

I have always been intrigued by a flowering tree whose acquaintance I first made in India, the *Bauhinia purpurea*, a species of that interesting genus whose name is derived from the related facts that its leaves are joined in twos at the base and that there lived and worked in the seventeenth century two Swiss brothers, scientific twins, members of a family celebrated as physicians and botanists. How appropriate that Caspar and Jean Bauhin should sponsor this interesting tree, now an adornment of many gardens all over the

world. In addition to *B. purpurea*, probably the most widespread and best known of the genus, with its large, showy, orchidlike pink flowers merging into purple, we have *B. triandra* or mountain ebony, closely resembling *purpurea*; *B. tomentosa* with yellow flowers; *B. krugii*, native of Puerto Rico; and many others whose fruit is a long, flat, beanlike pod.

Planted and encouraged to grow near Buddhist temples is often found another of my favorites, the Naka or Ceylon ironwood (*Mesua ferrea*). It prefers the hot and moist areas of British India, where during April and May this moderate-sized, conical, and handsome tree profusely blossoms as large, scented, white flowers with a yellow center of numerous stamens. New, deep crimson leaves appear twice a year, greatly adding to the beauty of an attractive species.

In the drier regions of India (one sees avenues of it on the road to Mount Abu) grows an erect 40-foot tree with large, broad, trifoliate leaves, the "flame of the forest" (*Butea frondosa*). During the dusty, rainless months when nature calls for some attractive living thing to cheer the passer-by this remarkable tree puts forth a profusion of beautiful crimson or orange-scarlet flowers whose flaming blooms justify its English vernacular name. It has, of course, many native titles, among them the dhak, mentioned by Kipling as a meteorological forecaster. When the tree blooms early and soon withers, the dry season will be prolonged and disastrous. The tree also produces a useful resin, called *kino*, and a valuable fiber. The young branches are a source of lacquer and the flowers are used in India for making orange and yellow dyes.

This partial catalogue of beautiful trees of north India would be incomplete without speaking of what is generally regarded as the most lovely of all the blossoming silva one meets with in the Far East. I refer to an originally Burmese tree, the *Amherstia nobilis*, named after Lady Amherst, the wife of a former British governor of Burma. H. F. Macmillan's description (*Tropical Gardening*, pp. 82, 83) of this silvan beauty as found in Ceylon gives a fine picture of the charming species, that combines in a wonderful way ornamental foliage with showy blossoms. The leaves, accompanied by

large graceful sprays of vermillion and yellow flowers, drooping from every branch and interspersed with the handsome foliage, present an appearance of astonishing elegance and loveliness. It is in blossom for the greater part of the year, except during long periods of rainy weather, the chief flowering season in Ceylon being from November to April. The tree grows to a height of 50 to 60 feet, is usually round-topped, with many slender branches and dark-green pinnate leaves. A remarkable feature is the long, hanging, brownish-pink clusters in which the young leaves appear. This habit is also characteristic,

to some extent, of certain other tropical trees as *Brownia grandiceps* and *Saraca indica* and *declinata*. In the latter case the young leaves are mottled pale gray or almost white.

The tree thrives in the moist low country up to 1,600 feet, and requires deep, rich, and well-drained soil. It does not seem to flourish near the sea, and is rarely met with about Colombo. It produces seed very scantily anywhere, a pod or two (which are flat, brown, 6 to 8 inches long, containing one to three large flat seeds) occasionally being all that can be obtained.

The genus *Cassia* furnishes many a beautiful, flowery tree species more or less widely spread over India, to the delight of the visitor. It is impossible here to do more than describe (briefly and inadequately) a few of the more attractive varieties.

The most interesting is, perhaps, *Cassia fistula*, the Indian laburnum, but also known by several other English and native vernacular synonyms. This is a rather small, upright tree and one of the most beautiful objects in the north Indian forests, where it prefers a dry or well-drained soil. When in full bloom, it suggests its common name, bearing masses of yellow flowers in pendant racemes. The blooms are, with the frangipani, much used as temple offerings while the astringent bark is used in medicine and for tanning. Another remarkable character of this laburnumlike shrub is its fruit—black, cylindrical pods that grow to a length of 20 or 30 inches, the pulp of which is a well-known laxative.

Although originally a native of South America, *Cassia grandis*, or the horse cassia, is found in north India. It is a spreading tree that attains a height of 40 to 50 feet, bears a profusion of pale pink flowers during the dry months, February and March (when it is completely deciduous), and in June produces numerous thick, coarse-skinned curved pods with an offensive odor.

A more attractive example of cassias is *C. multijuga*—a slender, quick-growing tree—indigenous to South America. It is in full bloom during August and September and is practically smothered with immense branches of bright yellow flowers, suggesting, as Macmillan says, a glorified tree calceolaria. It grows everywhere fairly well, but prefers a dry soil and climate.

Finally, during May and June a moderately sized, deciduous pink cassia (*Cassia nodosa*, so named because of its knotted stems) bears in great profusion lovely, bright-pink, rose-scented flower sprays. It is a native of Bengal and, like all the cassias, produces large pods—cylinders 12 to 15 inches long.

Trees that take kindly to all tropical and semitropical countries and to some temperate areas are several species of *Jacaranda*. I have seen many examples in both the New and Old World, including India, Ceylon, and California, although these trees are originally South American.

J. mimosafolia is a very beautiful species not only on account of its profusion of purplish-blue, bell-shaped flowers, but because of its elegant, mimosalike, bipinnate leaves. When the blooms are shed they form a thick blue carpet that characterizes this charming tree.

One of the most beautiful flowering trees of India (and of other tropical countries) is the iyavaki (*Peltophorum ferrugineum*), a large symmetrical tree of quick growth, indigenous to Malaya and Ceylon. It has a spreading top and fine feathery foliage. It blossoms irregularly twice a year, flowers and fruit often appearing at the same time. Its flowers, large, erect panicles, are scented and brownish yellow, and the tree when in full bloom presents a magnificent spectacle.

Of special interest to the traveler in India is the widespread appearance of the tree (or shrub) frangipani or pagoda tree (*Plumeria acutifolia*), a large, low, spreading shrub, quite bare of leaves, introduced from America. It is a familiar tree in almost every tropical country. In the Far East it is a well-known "temple tree," its strongly scented heads of white, yellow-centered flowers being a common offering at Buddhist altars. A scarlet variety (*P. rubra*) is very showy and remains in full bloom for several months.

A wonderfully beautiful and highly ornamental tree has spread by introduction into most tropical and semitropical countries. This is the famous *Flamboyante*, flame tree or golden mohur (of India). It originated in Madagascar and is now familiar to travelers because of its truly gorgeous flowers. It usually blooms in April and May, grows to a height of 40 to 50 feet, and with its spreading habit is well calculated to show a flaming top and handsome, long, feathery, bipinnate leaves. In many countries (British Guiana, Tahiti, India) I have seen avenues of these flame-colored tree tops whose glory must be seen to be fully appreciated. It is best known in America as the Royal Poinciana.

An Indian tree that originally came from West Africa is especially conspicuous from a distance because of its tallness and erect growth. This is the so-called tulip tree (*Spathodea campanulata*). I have noticed most of these in and about Kandy, Ceylon, where they serve the double purpose of shade and ornament. The large, erect, bright scarlet-orange flowers that crown the topmost branches of this handsome species make it a conspicuous object in even the distant landscape. The unexpanded flowers always hold considerable water that, scattered by a passing breeze, may be unexpectedly showered on the pedestrian beneath. This circumstance has given it one of its common names, the fountain tree.

Stenocarpus sinuatus, the Queensland fire tree, has taken kindly to north India, where it is occasionally seen. It is an erect tree 40

to 50 feet high, whose peculiar and very showy clusters of scarlet flowers are noticeable objects wherever they grow. It flowers from May to July at elevations from 1,500 to 4,000 feet.

Another important Australian species is the flame tree (*Sterculia acerifolia*), of medium size, a species with large, glossy, angular leaves, preferring high altitudes, at least up to 5,500 feet. It blooms in May and June when bare of leaves, producing brilliant masses of bright red blossoms.

Tropical fruit trees little known in America.—As every observing traveler in the Near and Far East knows, only a few edible tropical fruits have been widely grown and improved by scientific cultivation in American and other temperate climates. And yet there is no reason why many others should not be domesticated in the United States. As Macmillan has pointed out, certain tropical fruits, unsurpassed for their lusciousness and food value, are still capable of considerable improvement and of adaptation to a change of environment by "selective or asexual propagation, by budding, grafting, layering, cuttings, etc., or by hybridization and high cultivation."

These problems have long been considered by our highly competent and active Department of Agriculture, and it seems a wonder that some of the most obviously valuable of the long list of desirable tropical and semitropical trees are not more extensively utilized by American fruit growers in such localities as are suitable for their profitable adoption. One of the errors to be avoided in this connection is a slavish imitation of fruit-growing methods in the Tropics themselves, where as a rule the lines of least resistance are followed; for example, the lazy methods of seed propagation instead of more laborious though generally more profitable schemes involving careful selection of stock and its budding, grafting, fertilizing, regular pruning, and replanting. There is, of course, room to speak of only a few of these attractive and desirable fruits but little known in North America.

The sapodilla plum (*Achras sapota*)—in India sometimes improperly called mangosteen—or noseberry is a medium-sized (20 to 30 foot) tree with shiny, dark green leathery leaves, originally from tropical America but cultivated throughout India. An enthusiastic naturalist says of this russet applelike fruit (made up when ripe of a mass of soft, brownish pulp holding a number of easily separated large black seeds), "a more luscious, cool, and agreeable fruit is not to be met with in any country in the world." The sapodilla thrives up to 3,000 feet and usually bears two crops a year.

The papaya, pawpaw, or tree-melon (*Carica papaya*) is a small, fast-growing, branchless, herbaceous tree, from 15 to 20 feet high, widely cultivated throughout India. It bears a crown of long and

large palmate leaves at whose base the delicious, juicy "melons" are produced. These green-colored fruits are ovoid or round, 8 to 14 inches in length, 4 to 6 inches in diameter, and weigh from 5 to 10 pounds. One of the remarkable virtues of the tropical pawpaw is that it is in season the year round. Macmillan says of it:

The fruit has a central cavity, to the walls of which the olive-colored seeds are attached, usually in great abundance, but sometimes entirely absent. The succulent flesh is of a pinkish or orange tint, very refreshing and agreeable to the taste, especially on first acquaintance. It is generally esteemed as a table fruit, and is considered an aid to digestion. Some people prefer to eat it with a little sugar and fresh lemon or lime juice. It may also be made into jam or sauce, and in the unripe state may be pickled, or boiled and used as a vegetable. The seeds have a flavor like that of water cress. *Papaine*, a digestive enzyme, valued in medicine and in the preparation of chewing gum, etc., is obtained from the white, thin latex or juice.

The mangosteen (*Garcinia mangostana*) originated in the Malay States, but is now generally cultivated in India and Ceylon. This is one of the most delicate fruits of the Tropics and I enthusiastically indorse the claim that it partakes of the combined flavor of the strawberry and the grape. The tree is of small size and slow growth; the leaves large and leathery. The globular, purple-brown, smooth fruit looks like a small apple whose white, melting pulp surrounds several large seeds, the whole contained in a thick, inedible covering. This fruit is rather expensive, is regarded as a great delicacy, and is generally in season from May to July. Its cultivation (usually by seed) ought to be attempted as a delicious novelty in semitropical America.

The sugar-apple or sweet-sop (*Anona squamosa*) deserves mention as a candidate for domestic adoption in the warmer climates of North America. It originated in South America, where it is extensively cultivated, although little known north of the Mexican border. The tree, a small species, thrives in any ordinary, well-drained soil up to 3,500 feet and its fruit, maturing twice a year, generally in October and April, is the size and shape of a large apple whose yellowish-white, scaly or tubercular rind incloses a sweet, granular, custardlike pulp. There is also a purplish colored variety found in the West Indies.

It is passing strange that with so many varieties found in all tropical countries and probably suitable for domestication in most temperate climates that the useful mango is not more generally cultivated. The commonest species in India, where it is indigenous, is *Mangifera indica*, a large, quick-growing and wide-spreading tree whose panicles of scented, greenish-white flowers appear in January to March, the fruit in April to June thereafter. Some trees bear two crops a year. The ovoid fruit, flattened, with a distinct beak or projection at the apex, may weigh 2 pounds or more, but the usual

weight is about 6 or 7 ounces. It has a tough, yellowish-red or greenish rind inclosing the adherent flesh, which has a peculiar but pleasant aromatic taste. Inferior fruit may be tough, with a turpentine flavor. The single seed or "stone," to which the slippery pulp adheres very closely, is quite large. These characteristics make it a somewhat difficult task, until one has learned the art, to consume a ripe mango in public and at the same time preserve good table manners.

Macmillan remarks:

The mango is the fruit par excellence of India, where it has been cultivated from time immemorial. Here it may be considered an article of food as well as dessert, whilst it also enters largely in the preparation of chutneys and preserves. The tree thrives from sea level to about 3,000 feet or higher. A hot and rather dry climate, and a rich, deep, well-drained soil suit it best. The ground should be irrigated during prolonged drought, especially if the trees are setting fruit, also manured once a year, and mulched in dry weather. Pruning consists in thinning out superfluous or sickly branches; root pruning is sometimes applied with advantage to trees which become unfruitful, owing to their running too much into wood and leaf, the operation being performed by making a deep trench around the tree at a few feet from the stem and cutting clean all roots met with. Shade is not necessary, except when the plants are young. Propagation is best by grafting on seedling stocks of a hardy vigorous variety, or by in-arching or layering.

The largest, best-flavored, and most desirable varieties for general consumption that I have seen in north India come from Bengal, but the Indian mango has as many variants in size, flavor, color, and other qualities as the apple. It might well form a valuable and welcome addition to our supply of edible fruits.

There are many other tropical fruits awaiting domestication in more temperate climates which this short essay must ignore; I shall drop the subject with a brief mention of two species, both belonging to the luscious *Anonaceae*.

Number one, to be found in most tropical countries, I first tasted in British Guiana—the custard-apple, sometimes called bullock's heart (*Anona reticulata*). It is a small, bushy tree, found generally in low elevations, with a large brownish-red, round or heart-shaped fruit that contains several good-sized dark-brown seeds mixed with a sweet edible pulp. The latter resembles and tastes much like an agreeable custard, although the Indian natives have a superstitious belief that continued indulgence in it causes leprosy.

Second, the cherimoyer (*Anona cherimolia*). This species is now quite common in India and the Far East, a small tree introduced from Peru. The fruit is large, oblong, cordate or round, from 3 to 5 inches in diameter, covered with small pits and weighing from 2 to 4 pounds. It stands transportation very well and seems especially fitted for cultivation in California, Florida and other semi-

tropical States of the Union. Many authorities rank the cherimoyer with the pineapple and the mangosteen, and believe it to be far superior to its near relative, the *Anona reticulata*, which it most resembles. There are several cultivated races of this custard-apple, among them the quatemoyer and atemoyer, that differ from *A. cherimolia* chiefly in size and shape.

A subtropical fruit richly deserving of extensive cultivation in the United States is the passion fruit or sweet-cup, from *Passiflora edulis*. Originally from southern Brazil the passion flower has gradually spread over the tropical world, being met with frequently in Indian gardens and growing wild in the jungle. It is a perennial climber, flourishing at all elevations up to 5,000 feet. The fruit, of the shape and size of a hen's egg, is purple when ripe, the skin afterwards shrinking, like our wild perisimmon. It contains in its hollow center a quantity of fragrant, juicy, sweet pulp surrounding a number of small seeds. It bears transportation well, and its adoption as an edible fruit should be a domestic and commercial success. A delicious drink may be made from the soft parts by beating them up with water, a pinch of soda bicarbonate and sugar. This plant should be trained over a sheltered trellis or fence and grown in rich and moist humous soil. The appearance of the beautiful flower is said to recall the crucifixion—hence the name.

Although there is at my disposal not sufficient space even for a list of Himalayan birds (100 of them are figured in the first of the famous folios of John Gould, entitled "A Century of Birds from the Himalaya Mountains"), I can not pass by a few of these attractive species, all of them (or their close relatives) to be found throughout India.

Molyneux noticed among the birds of north India golden orioles, wagtails (white and yellow), kingfishers, herons, water-robins, buntings, gray tits, wren warblers, paradise flycatchers, bulbuls, thrushes, redstarts, pigeons, doves, and shrikes. He observed that the first golden oriole appeared on the 26th April—the same date as that on which it arrived the year before. Golden orioles have a glorious deep, liquid, flutelike note which thrills through the whole garden. Two or three pairs always settle there, and all day long their brilliant yellow plumage is seen flashing from tree to tree. Three days later another brilliant visitant appears, the paradise flycatcher. He has not the beautiful note of the golden oriole, nor such striking plumage. But he has exceedingly graceful form and movements. He has a very long, wavy, ribbon tail, like a paradise bird, and the two or three pairs of them which yearly settle in the garden may be seen at any hour undulating through the foliage or darting swiftly cut to catch their prey.

It may be added to these observations that it is the black-naped oriole (*Oriolus indicus indicus*) that is seen in the Indian northwest, the black-headed variety (*O. luteolus luteolus*) being rarely found in that locality, although it is common enough throughout the rest



A VIEW OF THE FAMOUS SHALIMAR GARDENS, KASHMIR, WITH THE MAHA-DEV
IN THE DISTANCE



1. A VIEW IN THE FAMOUS SHALIMAR GARDENS, KASHMIR



2. THE CHENAR TREES IN THE GARDENS OF THE NISHAT BAGH, DAL LAKE, KASHMIR

of the Continent. The beautiful mixture of deep black and bright yellow in the plumage and the rich notes of their song render both species conspicuous as well as charming attractions in forest and garden.

It may be added to Molyneux's notes regarding the paradise fly-catcher (*Terpsephone paradisi paradisi*) that the species is one of the most remarkable birds of the Himalayas; indeed of all India. The females and young birds (and males until their second summer) have glossy blue black as the predominating color of the head and upper parts. This gradually runs into ashy brown on the breast and to white on the abdomen. The tail is about $4\frac{1}{2}$ inches long. In his second year the cock, whose average length is 18 inches, is almost transformed. He becomes more glossy black than before and the two central feathers of his tail grow to a length of 12 inches or more. In the fourth year the whole head, neck, and crest become a deeper metallic black, while the remainder of the body plumage, including all the tail feathers, is distinctly white; in fact in his flight through the jungle one sees a wonderful black-headed *white* bird with a long white tail quite unlike his mate or indeed himself of the year before. There are at least two variants of this conspicuous species found in India and Ceylon.

The hoopoe (*Upupa epops*), celebrated in literature from the earliest times, is not unknown to the people of Europe, having until recent years made its appearance as far west as the British Isles where on several occasions it has nested and bred. Doubtless this beautiful bird might have established residence there had it not been shot down by barbarians as soon as seen. The hoopoe is about 12 inches in length, with a long slender bill slightly curving from base to tip and a large, conspicuous crest capable of being erected or folded at will. Of its variegated plumage it may be said that the head and neck are golden buff, the broad-feathered erectile crest being tipped with black and barred near the terminals with yellowish. The upper back is reddish; the flight feathers are black broadly crossed with white. The long square tail is black with a marked white chevron. This combination of form and color produces markings that render the bird conspicuous even at a considerable distance.

I have had many opportunities of observing the Indian hoopoe at close range; for a couple of months several pairs were my frequent companions at a game of golf on the links at Srinigar. They were quite tame and kept only a few yards out of range of golf balls. As my drives and other shots were not long, I had many opportunities of making notes of their feeding methods (there were numerous insects to be had for the catching), the manner of raising and lowering their remarkable crests, their disputes, love making, etc.

Although it is much commoner in the Himalayas than in southern India or Ceylon, it happened that I had in the latter country my first and several subsequent visits with that most beautiful of the smaller Asiatic birds of prey, the Indian peregrine falcon. I was one day collecting specimens of small birds near the famous Sigiriya Rock in the wilds of central Ceylon when like a bolt from the blue the bird that I was hunting was snatched from before my very eyes by a little hawk that I had seen a short time before flying about in the neighborhood. In a minute or two he (or she) reached the security of a near-by cliff with the body of what should have been my bird. For several days I had ample opportunity of studying this pretty peregrine falcon (*Falco peregrinus peregrinator*), called in the vernacular the shahin (or shaheen). As usual with birds of prey, the female is larger than the male, in the former case nearly 18 inches long; wing, 13.50 inches. The head and nape are jet black and the under parts from chest to tail coverts a deep, rich brown. The mandibles are slate blue; cere and periorbital skin and legs yellow; iris dark brown. The shahin is a shy and rather rare bird, difficult of approach, frequenting ledges of high cliffs and feeding exclusively on relatively large quarry, such as pigeons, swifts, swallows, and parrakeets. Its swoop is as swift, bold, and sure as that of the larger peregrines. The shahin is famed in the literature of sport, its praises and exploits as a brave, courageous, and beautiful "bird of chase" being sung and depicted in many works on falconry.

I wish it were possible for me to describe some of my favorite Indian babblers—a numerous subfamily (*Timaliinae*) well known in the East. (Parenthetically, this group does not deserve its trivial name of "babblers.") One species is well known under the vernacular name of the seven sisters (*Turdoides griseus striatus*). This synonym is derived from the habit of going about in little groups of from five to seven individuals, probably all members of the same family. The "sisters" are tame, slow-moving, grayish-brown birds, about 10 inches long, with white irides and yellowish eyelids, that love to move about in cultivated localities or in the near-by jungle.

The vernacular name of *Pomatorhinus melanurus* Blyth is the scimitar-billed babbler, derived from its long curved bill. It differs in many characters from other species of the subfamily, and is rarely found outside the Himalayan Range, although a subspecies, *Pomatorhinus horsfieldii melanurus*, is not uncommon in Ceylon. It is a shy, forest race and, like its northern relative, is usually found in pairs. The north Indian variety is rather uniformly dark brown with a whitish throat and a plainly marked white superciliary streak from nape to bill, and is 8½ inches long. The curved mandibles measure nearly 2 inches in length.

A DECADE OF BIRD BANDING IN AMERICA: A REVIEW

By FREDERICK C. LINCOLN

Biologist, United States Biological Survey

[With 5 plates]

From its inception in 1885, the study of North American birds by the Biological Survey of the United States Department of Agriculture has continued to be a major activity of this bureau. The distribution, migration, and economic status of birds have claimed the attention of its specialists for nearly 50 years, and the leadership of the bureau in these fields of research continues to be demanded. Since practically every method advocated for the development of new information has been thoroughly tested by the bureau, it is not surprising to find that, with the active cooperation of Canadian officials, it is directing one of the greatest studies of avian life ever attempted, namely, that conducted through a continental system of cooperative, volunteer, bird-banding stations.

In the Report of the Smithsonian Institution for 1927, under the title "Bird Banding in America" (pp. 331-354, 1928), the author presented a historical sketch and account of the development of the work during the preceding five years. Another 5-year period has now elapsed, and in concluding this full decade of intensive effort, it is fitting, in retrospect, to view the accomplishments.

Any new field of research is usually divisible into three periods: First, experimentation, when methods are developed; second, data accumulation; and third, interpretation and report. Properly speaking, none of these has an ending, as the perfection of technique and the testing of new methods and refinements continue indefinitely, as may also the collection of usable data. A starting point for the third period is, however, dependent wholly upon the successful prosecution of the other two, as obviously, no interpretation can be prepared until sufficient material has been obtained to permit proper evaluation. The banding work, as applied to North American birds, has only within the last few years entered this third period. During the 10 years many reports of more or less fundamental importance have been issued, but the data applicable to the larger ornithological

problems have only recently accumulated in adequate quantity, even for those species which from the beginning have received most attention.

As a means of illustrating the growth of the project—which reflects also the great interest in this means of investigation that has developed among the bird students of the continent—an examination of Table 1, showing the gross results, will be of interest. The fiscal years are those of the Federal Government, that is, beginning July 1 and ending June 30.

TABLE 1.—*Progress of bird banding in America*

Fiscal year	Number of coo- perators	Number of birds banded	Number of re- turns ¹	Fiscal year	Number of coo- perators	Number of birds banded	Number of re- turns ¹
1921-----	135	2,845		1928-----	² 1,400	127,105	7,222
1922-----	490	5,940	149	1929-----	² 1,500	133,931	² 8,500
1923-----	851	25,068	668	1930-----	² 1,750	182,263	² 10,000
1924-----	890	40,432	1,924	1931-----	1,869	169,279	12,329
1925-----	1,100	64,253	3,187	1932-----	1,976	212,146	³ 11,789
1926-----	1,134	68,418	3,351				
1927-----	1,296	91,848	4,445	Grand total--		1,123,525	63,564

¹ As applied to the bird-banding work a "return" is the record of a banded bird retrapped from the same or any other station during or following the succeeding migration period, and also banded birds that are killed, either accidentally or otherwise, regardless of the elapsed time since they were banded.

² Approximate.

³ The reduced number of return records for the fiscal year 1932 is explained by the reduction of the shooting season for waterfowl from 3 months to 1 month in the fall of 1931.

When the work was started it was natural that those species to be banded in largest numbers should be the common frequenters of our dooryards, usually easily captured by the traps and methods then known. The results of the pioneer work of Dr. S. Prentiss Baldwin (1919) involved the use of traps originally developed by the Biological Survey for the control of English sparrows. His report became the first textbook and the foundation upon which the structure of future activities was laid. It was immediately obvious, however, that with our great and varied avifauna, there existed a vast field to tax the ingenuity of station operators in devising efficient means for bringing additional species within the scope of the work. The capture of the ground feeders, which respond readily to cereal baits is a comparatively simple matter, but the insect feeders and particularly those whose field of action is chiefly in the tree tops presented a much more difficult problem.

The large and interesting family of wood warblers for several years defied the efforts of station operators to trap them. Many elaborate traps were worked out and pulled high in the trees by means of endless ropes and pulleys, while bait items ran a long gamut, mostly without success. Finally it was discovered that "live" water, that is, water in a state of motion, had a potent at-

traction for these birds, and would frequently bring them to the ground (pl. 1 and pl. 2, fig. 1). With this knowledge, progress was rapid until now many stations are taking them in considerable variety and number. For example, a report recently received by the Biological Survey, following the spring migration of 1932, contained the banding records for 155 warblers of 19 species, while reports from other points show similar success.

Some of the author's early work in the field of banding had to do with the development of a satisfactory trap for ducks. The traps that had been used by market hunters were known, but generally these were found to be unsatisfactory for banding work. A short period of experimentation, however, resulted in the perfection of a simple trap that gave excellent results when used for mallards, black ducks, pintails, and other shoal-water species. Success here was somewhat discounted by the skeptics who openly declared that it would be a different matter when operations were begun with canvasbacks, redheads, scaups, and other deep-water species. It was a different matter, but already several thousands of these ducks have been banded (pl. 2, fig. 2, and pl. 3, fig. 1). In fact it is now a maxim with bird banders that "there is a way to trap everything if you can only solve the problem," and "you can trap any species for which you can discover an attractive bait."

The smaller tree climbers, such as the brown creeper and the black and white warbler, presented another problem. As these birds ascend the trunk of a tree it had been noticed that if they met any kind of an obstruction, they generally flew to another tree. It was found, however, that if the barrier slanted upward, the birds would continue to ascend, keeping a short distance away from the obstruction. Upon the basis of this observation, William I. Lyon, of Waukegan, Ill. (1924), worked out a highly successful trap for taking these birds (pl. 3, fig. 2, and pl. 4). A collar of wire netting, tacked to the trunk of the tree in an ascending spiral, serves to guide the climbing bird into the trap chamber.

GAME SPECIES—WATERFOWL

From the beginning of the project, the Biological Survey has given all possible attention to the banding of large numbers of migratory waterfowl, confidently believing the resulting data would be most useful in its administration of this important natural resource. Table 2 illustrates in part the success that has attended these efforts. With the data represented in this table available, valuable contributions may be made to the problems of conservation. The following summaries are based on studies already made or in progress.

TABLE 2.—*Banded waterfowl*

Species	Number banded	Number of returns	Species	Number banded	Number of returns
Mallard.....	40,369	8,036	Cinnamon teal.....	562	38
Black duck.....	14,346	2,883	Shoveler.....	346	63
Gadwall.....	671	113	Redhead.....	3,149	545
Baldpate.....	2,883	633	Ring-necked duck.....	2,083	241
Pintail.....	15,207	2,512	Canvasback.....	752	100
Green-winged teal.....	3,022	408	Lesser scaup.....	9,699	591
Blue-winged teal.....	2,741	332			

Migration.—Study of the distribution and migration of North American waterfowl continues to be a major project of the Biological Survey, and as will be noted from the data contained in Table 2 the number of banding records applicable to this subject is increasing rapidly.

A detailed investigation of the distribution and migration of the mallard and the black duck, two of the most important species of game waterfowl, is now in progress. Several thousand return records are at hand, which make it possible not only to present in full detail the intricate movements that make up the semiannual movements of these birds but also to portray graphically the way the flocks sweep across the country. While ornithologists and sportsmen have long understood the existence of migration flyways, along which birds are more or less concentrated, there has been a tendency to consider these lines of arterial traffic as narrow lanes, rather than as broad boulevards. The banding records show the general routes followed and also their approximate widths. From a study of these data a new type of migration map (fig. 1) has been devised to illustrate the advance and spread across the country of the ducks from any particular breeding or concentration area. Several maps of this type will show the movement of a species from different areas, and when these are superimposed on each other the resulting map should present an easily understood picture of the entire migratory flight for that species.

As will be seen from the map (fig. 1), ducks banded in the Prairie Provinces of Canada, in the autumn move both southeast and southwest. In fact, the great flocks of canvasbacks and redheads that winter on the Atlantic coast come chiefly from the interior breeding ground.

The banding work early showed that during the migratory season there is very little interchange of waterfowl between the eastern and the western halves of the country within the United States, even with those species that have a more or less general continental distribution. On the breeding grounds in central Canada the eastern and western ducks intermingle freely, but when the time comes for

migration they separate and each group adheres to its ancient fly-ways. The proof of this lies in the fact that very few ducks banded in the United States east of the one hundredth meridian (central North Dakota, South Dakota, and Nebraska, western Kansas, and central Texas) are killed west of this line while in the United States, and vice versa.

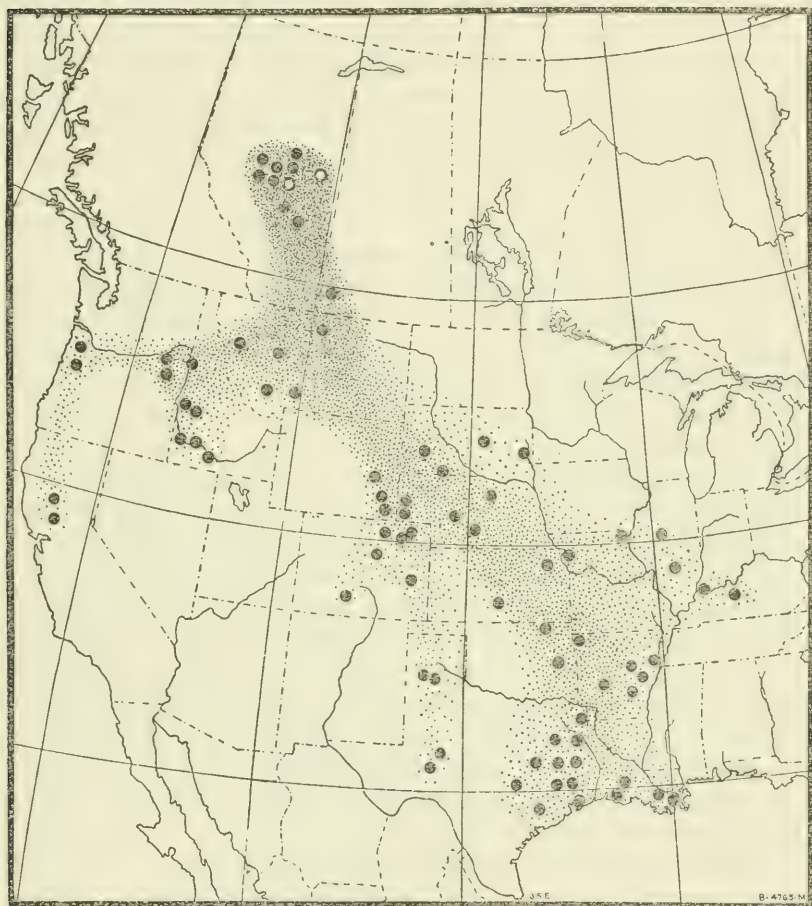


FIGURE 1.—The autumn migration of mallards from Alberta. Each large spot indicates the point of recovery of a banded duck while the shading shows the relative density of the flight in the different regions

The significance of this discovery will be more readily understood by reflecting upon the present condition of our wild waterfowl. During recent years drought conditions, disease, overshooting, and other unfavorable factors have been disastrous to these birds, chiefly those inhabiting the western part of the country. Some species (notably the diving ducks) that visit the eastern district have also been seri-

ously reduced, while others, such as the mallard and the pintail, that frequent the eastern plains region, the Mississippi Valley, and the Atlantic coast, have not been so much affected. It is easy to conceive that these conditions might become so acute that a complete cessation of wildfowl hunting would be imperative all through the West; possibly important species of migratory game birds might be virtually extirpated over vast areas in this part of the country, and at the same time be fairly abundant east of the one hundredth meridian. The banding records indicate that should such a disaster overtake these birds, those that migrate through and winter in the East would be very slow to overflow and repopulate the devastated areas in the West even though a complete recovery of natural habitat conditions might be achieved.

There are, of course, very well-defined northwest by southeast flights of ducks, best illustrated by considering the line of migration previously mentioned and which is followed by redheads and canvasbacks in reaching the Atlantic coast from their breeding grounds in central Canada. These birds follow the general line of the Great Lakes and thence overland to Delaware and Chesapeake Bays. Such flights are not to be confused with the more nearly north and south routes of the interior.

Nevertheless, occasionally ducks banded at eastern stations are recovered subsequently at points in the West as the following cases will illustrate: A mallard (231104) banded at Browning, Ill., on November 30, 1922, was killed near Sacramento, Calif., on December 24, 1923; a blue-winged teal (323756) banded at Lake Scugog, in southern Ontario, on September 24, 1925, was recovered in San Francisco Bay, Calif., on December 12, 1926; a pintail (367029) banded at Ellinwood, Kans., on March 4, 1925, was retaken in Butte County, Calif., on December 19, 1925; a greater scaup (204206) banded at Union Springs on Cayuga Lake, N. Y., on February 27, 1923, was killed at Big Lake, Wash., on December 7, 1927; and a lesser scaup (322327) banded at Oakley, S. C., on March 6, 1925, was recovered in Berkeley County, Calif., on January 13, 1926.

State dispersal of ducks.—In those States so fortunate as to have abundant waterfowl there are always centers of abundance, that is, areas of great importance to these birds as breeding grounds in summer or as feeding and resting grounds in winter. During the past 10 years many of these areas have supported active waterfowl-banding stations among which may be mentioned Lake Merritt, at Oakland, Calif., Lake Malheur, Oreg.; the National Bison Range, western Montana; the Bear River Marshes, at Great Salt Lake, Utah; Dawson, N. Dak.; the Cheyenne bottoms, Kansas; the marshes of the Illinois River, central Illinois; Cuivre Island and Portage des Sioux,

Mo.; Avery Island and the Paul J. Rainey Wild Life Refuge, La.; Waco, Tex.; Green Bay and the Moon Lake Wild Life Refuge, Wis.; Munuskong State Park and the Kellogg Bird Sanctuary, Mich.; Rochester and Long Island, N. Y.; Bar Harbor, Me.; Cape Cod, Mass.; the coastal marshes of South Carolina; and the lakes of southern Georgia. In Canada important stations have operated at Lac Ste. Anne and Leduc, Alberta; Muscow and Yorkton, Saskatchewan; and Kingsville and Lake Scugog, Ontario.

Sportsmen and conservation officials are keenly interested in knowing the dispersal of the ducks that concentrate at one season or another in these areas. Also, such information is highly practical from the viewpoint of game administration, in indicating the regions that may require special measures for their protection, such as the establishment of refuges. For example, during the time that the act which created the Bear River Migratory Bird Refuge in Utah was pending in Congress, some opposition developed from a group of California sportsmen who contended that the number of hunters concerned with this area was too small to justify expenditure of the funds that were contemplated. The records of ducks banded in these great marshes showed conclusively that the big flights of birds to California came through or from this section. When the data were shown on a map and made public, opposition quickly subsided. Similarly a map showing the dispersal of ducks banded in the Cheyenne Bottoms, Kans. (fig. 2), played an important part in the establishment of a Federal migratory-bird refuge at this point.

Calculating waterfowl abundance.—A major problem of sportsmen, naturalists, and conservation officials is the effect upon the supply of waterfowl of the annual kill by hunters. It is important to know whether the sportsman is merely harvesting the increase or whether he is also cutting into the breeding stock necessary for the perpetuation in adequate numbers of the different species. The many factors involved make the solution of this problem extremely difficult, and it will be apparent that the mere opinion of any single observer or group of observers can be accorded little weight unless it is known that all pertinent data have been taken into consideration. Nevertheless, it is believed that the most important factors may be calculated or at least estimated with accuracy sufficient for practical purposes. If this be true, then it appears that data from banded ducks will offer a reliable method for computing the annual fluctuation in the abundance of these birds. The basis of this belief is the constant relation that seems to exist between the number of ducks banded and the number of these killed during the first succeeding hunting season.

Briefly stated, the solution of this part of the problem may be found in the following postulate: Given a fairly accurate statement of the number of wild ducks killed in North America in any one season, the total number of ducks present on the continent for that

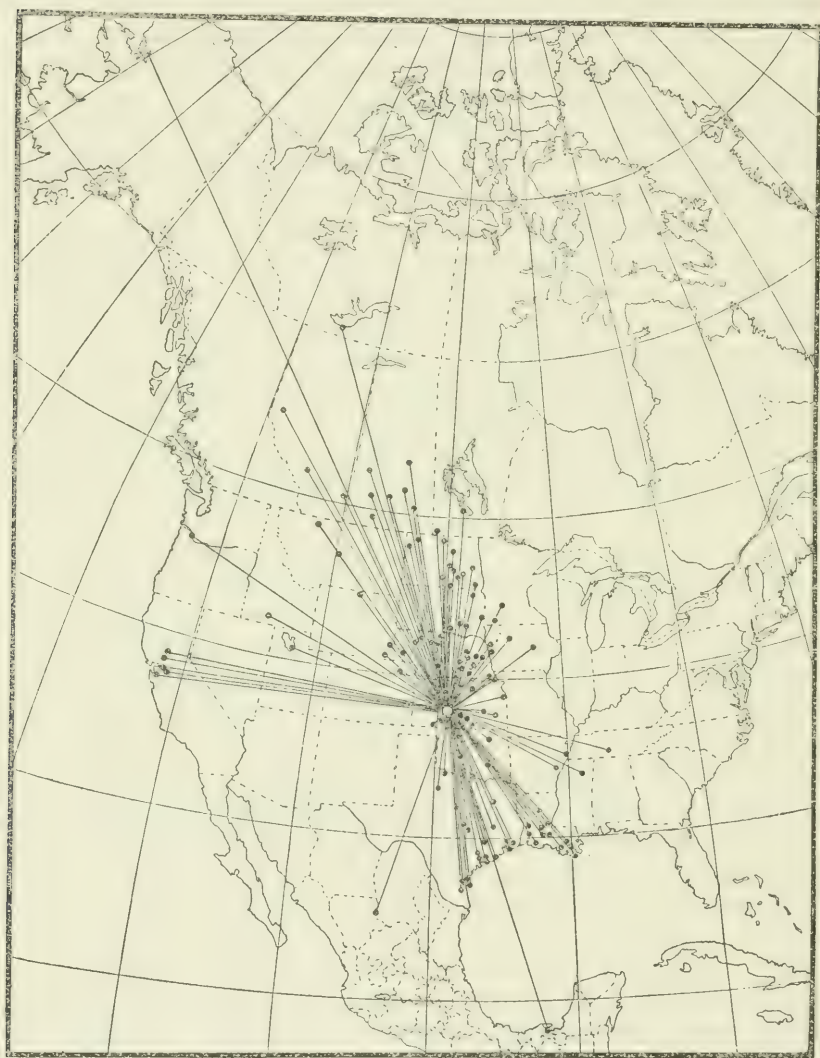


FIGURE 2.—The dispersal of banded ducks from the Cheyenne Bottoms, Kans.

season may be estimated by a percentage computation based upon the ratio that the total number of banded ducks killed during their first season as band carriers, has to the total number banded. (Cf. Lincoln, 1930.)

TABLE 3.—Percentages of returns throughout the country of banded ducks during the shooting season immediately following their banding, 1920-1926

Year	Number banded	Number of returns	Percentage	Year	Number banded	Number of returns	Percentage
1920-----	238	31	13.03	1925-----	1,795	214	11.92
1921-----	382	52	13.61	1926-----	4,891	444	9.08
1922-----	3,774	572	15.16	Total or average--	17,449	2,083	11.94
1923-----	4,103	438	10.68				
1924-----	2,266	332	14.65				

Table 3 shows this relationship and the percentages based on the material available after seven years' work. The average of about 12 per cent is slightly increased when the results from the different banding stations are considered separately, the average first-season recoveries being between 12 and 13 per cent. Twelve per cent, however, is very close to a general average and may be accepted as a basis for computation, particularly when it is remembered that we are dealing with a problem in which the units are to be shown in millions. Disregarding other factors (which are, however, of decided importance), an illustrative case may be assumed as follows: If in one season, 5,000 ducks are banded and these yield the expected 600 first-season returns, or 12 per cent, and during that same season, the total kill is determined at 5,000,000, then the waterfowl population for that reason was approximately 42,000,000. To assume further: If during the following season (both seasons of equal length), the total kill is estimated at 500,000 birds less, then the total duck population for that year would be about 37,500,000, or an approximate decrease of 4,500,000 in the continental waterfowl population.

Such figures naturally should be considered only as approximations but they would at least have the merit of being based on factors appearing to have a definite relationship. As the work continues, additional data are being accumulated so it should be possible ultimately to arrive at an average percentage in which the margin of error will be reduced to a negligible quantity.

Sex ratio.—It is common knowledge among sportsmen that the average bag of ducks is likely to contain more males than females. This, however, is not surprising, since it is fairly obvious that in a mixed flock of both sexes the aim of the shooter would unconsciously be directed toward the males because of their more striking and conspicuous plumage.

But it would seem that the large cage traps used to capture ducks for banding can not be selective as regards sex. As a matter of fact, observations of the author on one species, the pintail, indicate the

females to be less suspicious than males, which are frequently led into the traps by their consorts. Nevertheless, as early as 1922, while experimental work to develop a satisfactory duck trap was in progress a total "catch" of 388 mallards was divided into 248 males and 140 females, or a ratio of a little less than two to one. Personal experience since that time in other regions, at other seasons and with other species has indicated a corresponding preponderance of males over females. Also, the operators of other waterfowl banding stations frequently have commented upon the relatively large numbers of males that were trapped in proportion to the females.

Generally speaking, all birds are naturally monogamous, so theoretically it would seem logical to assume a reasonably perfect numerical equality of the sexes. This condition has been borne out by investigators who have studied the sex ratio of the domestic fowl. For example, Darwin worked out the ratio as 48.64 to 51.36 in favor of the female, while more recently Prof. Raymond Pearl, of Johns Hopkins University, working on a basis of 22,000 chicks, obtained a ratio of 48.57 to 51.43 males to females, thus giving almost perfect confirmation to the pioneer results of Darwin. The apparent situation among our waterfowl appears, therefore, to warrant serious study.

As a contribution to the subject the author has made (1932) a statistical analysis of the banding data for certain species of ducks. The material available for study consisted of banding records from about 50 trapping stations located geographically from Maine, Connecticut, and South Carolina, west to California and Oregon, and from Alberta, Saskatchewan, and Michigan, south to Georgia, Louisiana, and Texas. The data represented 10 of the most important species of game waterfowl and totaled 40,904. This was only a little more than half of the grand total of banded ducks, but certain lots of records were considered ineligible for inclusion in the study for various reasons. Among these were the unknown ability of some operators to sex their birds, particularly in late summer and early fall when the plumage of immature birds closely resembles that of the females. In other words, all data that in any way might be considered as open to question were excluded from the study.

The proportion of sexes in the total number was 24,411 males to 16,493 females, or about three males for every two females. The detailed comparison shown by species is well illustrated in Table 4.

The results shown in the gross numbers are similarly borne out by the records from the individual stations, in some cases the proportion being even greater. For example, of 415 mallards banded at Dawson, N. Dak., in the autumn of 1926, 309 were males and 106 were females, or a ratio of nearly 3 to 1.

TABLE 4.—*Percentage of males in banded ducks*

Species	Males	Females	Percent- age of males	Species	Males	Females	Percent- age of ¹ males
Wood duck.....	391	367	52	Lesser scaup.....	2,633	1,444	65
Mallard.....	12,386	9,572	56	Blue-winged teal.....	765	411	65
Black buck.....	477	344	58	Green-winged teal.....	357	95	79
Baldpate.....	413	251	62	Ring-necked duck.....	455	123	79
Pintail.....	6,308	3,759	63				
Canvasback.....	226	127	64	Total.....	24,411	16,493	59

¹ In the computation of percentages the figures have been carried to the second decimal, and the remaining fraction, if less than 0.5, has been dropped, while if more than 0.5 the next higher unit has been adopted.

It will be observed that in the case of the wood duck, there is a more normal representation of what might be properly expected as a sex ratio. As this handsome bird for 16 years has enjoyed comparative immunity from shooting, the conclusion seems to be fairly well justified that overshooting has been responsible for the disproportionate ratios in the other species. Possibly this is the correct solution, but further study of the problem will be required before the full significance of the data will be apparent. Nevertheless, despite the seeming truth of the hypothesis that more males than females are killed by hunters, it appears obvious the drakes now outnumber the hens in a proportion that does not auger well for the successful rearing of broods of ducklings.

NONGAME SPECIES

Banding problems dealing with nongame species, and which engage the attention of the Washington staff of the Biological Survey, relate almost entirely to distribution and migration. Contributions to this subject by individual station operators obviously can have only local significance for the reason that interpretation of the data assembled from points over the entire hemisphere can be satisfactorily made only at the central office. There are, however, exceptions, as occasionally a station operator will obtain an adequate quantity of data from his own birds, or he may be able to coordinate the activities of several widely scattered stations and so be placed in possession of sufficient material to warrant interpretation. The following examples, dealing with the evening grosbeak and the Harris sparrow, illustrate the case in point.

East and west migration.—The general (and usually correct) conception of bird migration is of a north and south movement. In addition, for many years we have been familiar with what is known as "vertical migration" whereby mountain-dwelling species obtain latitudinal changes in habitat by the simple expedient of moving down the mountain sides in the autumn and back again in

the spring. It now appears, however, that some birds make east and west trips with the same regularity of others in their journeys between the North and the South. The evening grosbeak (*Hesperiphona vespertina*) is an excellent example.

This large finch breeds almost entirely in the Canadian Zone, and while it is a notorious wanderer, it is detected only occasionally as far south as Missouri, Kentucky, and Maryland. At one banding station, operated at Sault Ste. Marie, Mich., it is plentiful, and many are banded each year. From these, several return records are available, the points of recovery extending west to Karlstad, Minn., and east to eastern Massachusetts and Connecticut (Magee, 1930). Altogether some 9 or 10 records indicate the remarkable "sidewise" movement of this bird. In addition to those banded at the Michigan station and recovered at eastern and western points, one was there recaptured which had been banded at Hanover, N. H.

Banding records for other species indicate that east and west movements may not be as unusual as has been believed.

A coot (A515245), banded at Green Bay, Wis., on October 22, 1930, was killed at Essex, Conn., on November 5, 1930.

A duck hawk (A701032), banded at Mohonk Lake, N. Y., on June 18, 1929, was recaptured at Grand Island, Nebr., on September 26, 1929.

A chimney swift (A37826), banded at Thomasville, Ga., on October 3, 1925, was captured at Claremore, Okla., on June 6, 1928, and again on May 8, 1929.

A blue jay (A346309), banded at Hubbard Woods, Ill., on May 13, 1930, was recovered at Bluevale, Ontario, on February 24, 1931.

A purple finch (A124752), banded at Katonah, N. Y., on April 23, 1930, and another (C69545), banded at Sault Ste. Marie, Mich., on August 17, 1930, were retrapped together at Milton, Mass., on February 14, 1931.

Another purple finch (A54292), banded at Cohasset, Mass., on January 30, 1927, was retrapped at Pickford, Mich., on March 10, 1929.

A junco (84691), banded at Crystal Bay, Minn., on October 13, 1923, was retrapped at Demarest, N. J., on January 9, 1926.

Another junco (A61943), banded at Paoli, Pa., on November 6, 1927, was retrapped at Jamestown, N. Dak., on April 23, 1928.

Harris sparrow.—An important contribution to our knowledge of this little-known species has been made by Swenk and Stevens (1929). The junior author, himself the operator of one of the larger banding stations, established contact with six other stations where Harris sparrows were common and so added greatly to the data for his study. The records from one station (Fairbury, Nebr.) showed a

remarkably large percentage of these birds returning to winter in the same place. For example, of 13 birds banded in February, 6, or 46.1 per cent, returned the following year. Data obtained at Fargo, N. Dak., indicated that the southward migration of the adults is more rapid than that of the immatures. In 1928, 38 adults stayed in the vicinity of the banding station for an average of only 2.4 days, while the immature birds made stop-overs averaging 8.7 days.

The return to exact winter quarters of certain birds has been demonstrated on several occasions, perhaps the best example being a small group of banded white-throated sparrows that returned year after year to a patch of ornamental shrubbery on a plantation at Thomasville, Ga. (Cf. Baldwin, 1922.) Other stations have had similar experience with juncos, chipping sparrows, and other finches. This habit appears to be fairly well established for several birds, but it also appears that all individuals may not make the same stops while on their migratory journeys. The best evidence of this comes from a banding station at Waukegan, Ill., where more than 6,000 white-throated sparrows have been banded. A few return records for these birds have been reported from other points, but up to the present time (July, 1932) the operator of this station has not recaptured in a successive season a single banded white-throat.

Studies at banding stations.—Among the published reports of the past few years there are intimate studies dealing with local movements and other habits of certain birds, some of which are usually considered to be more or less resident in their respective areas. It is in investigations of this kind that the individual station operator comes "into his own," as it is practical for him to work out his entire problem without the necessity for access to data from other points. To be sure, before the results obtained in one area can be considered as being applicable to the species over its entire range, a certain amount of repetition must take place in other sections, but this in no way militates against the completion by a single worker of a definite piece of research.

The species that have been accorded this treatment include the song sparrow, the house wren, the white-breasted nuthatch, the tufted titmouse, and the chickadee. In some of these studies the permanent registration of the numbered aluminum band has been supplemented by second bands of colored celluloid which enabled the investigator to keep individual birds under more or less continuous observation, without the necessity for frequent retrapping.

Dr. Wilbur K. Butts (1930 and 1931), after much experimental work involving the use of stains, dyes, and enamels, devised a method for the manufacture of small celluloid bands. These are now stocked regularly by the Biological Survey. Doctor Butts conducted an

exhaustive inquiry into the local movements of the chickadee (*Parus atricapillus*) and the white-breasted nuthatch (*Sitta carolinensis*) on the Cornell University campus and the nearby Louis Agassiz Fuertes Bird Sanctuary. The study was begun in the autumn of 1924 and continued (with interruptions of a few months at a time) to 1929. During this period practically all of the chickadees and nuthatches within the area were banded both with a numbered aluminum band and a colored celluloid band.

It was found that during the winter season there were four or five times as many chickadees present as during the breeding season, which possibly indicates a migration of certain individuals, although the breeding birds of the area were all, or nearly all, permanent residents. The influx of birds from other regions occurred between August and January 1, while most of these transients left in March and April. Chickadees are known to wander in small flocks, but it was ascertained that these were not, as might be otherwise expected, family parties. Nevertheless, the flocks behaved as semi-permanent units and had definite restricted feeding territories of from 40 to 70 acres. When nesting it was found that the birds ranged about 100 yards from the nest, although most of the food was obtained much nearer. When one member of a mated pair suffered an accident or disappeared for any reason, the survivor frequently obtained a new mate, and it was determined that the fact of an adult raising a brood of young could not be accepted as *prima facie* evidence that it was caring for its own offspring. In this species at least, the young finally disperse widely from the nest.

In the case of the nuthatch Doctor Butts found that there was no evidence of migration in the region of Ithaca, N. Y., and that the birds he studied were permanent residents. These birds ranged in both summer and winter over areas approximately equal in size, but they showed no hesitation in changing the scene of their operations in the different seasons. In addition to mated pairs which have established their territories, there are usually a number of wandering unmated birds which may take the place of one member of a pair if for any reason it disappears. It was also found that the parents had little difficulty in finding ample food for their broods close to the nests and Doctor Butts concluded that feeding the young is not as severe a task as it is commonly supposed to be.

A somewhat similar study has been made of the tufted titmouse (*Parus bicolor*) by Mrs. Mabel Gillespie (1930). Field observations, supplemented by banding data over a period of 12 years in the vicinity of Glenolden, Pa., resulted in an important accumulation of data. In recent years the possible influence of the sun-spot

cycle on population density and scarcity among various forms of life has received much attention from some biologists. According to the theory of Julian Huxley (1927) meteorological conditions of the earth which are caused periodically by sun-spot maxima result in conditions favorable for increased productivity of plant life, and, therefore, of herbivorous animals and their predators. Epidemic disease then causes numerical reduction to the minimum when the cycle is repeated. It has been found that the average length of this cycle is either a little more than 11 years, or else is one-third of this, and Mrs. Gillespie finds in her data a striking suggestion of a 4-year cycle for abundance in the tufted titmouse. In the words of Mrs. Gillespie: "The results of 12 years' observations show a tendency toward alternate years of presence and absence about the banding station or near vicinity; and a peak of population density every four years, followed by a scarcity of numbers."

The song sparrow (*Melospiza melodia*) is not only one of the most widely distributed of our native birds, but also one of the sweetest singers. Added to these qualities is its general willingness to associate with human habitations. Taking advantage of a local concentration of this species, Mrs. Margaret Morse Nice (1930, 1931, and 1932) has conducted a most interesting and important investigation at Columbus, Ohio.

In the region under consideration the song sparrow attempts to raise three broods, sometimes producing a fourth set of eggs if one or more nests meet with disaster. During the incubation period the average routine for the female is between 20 and 30 minutes on the eggs, alternated with feeding periods of 7 to 9 minutes. There does not appear to be any set time, however, as either period may be longer or shorter.

One of the features of this study has been a careful investigation of the territory requirements and its occupation. In the vicinity of Columbus it was found that about half of the males are permanent residents which appear to spend their entire adult lives within the space of a few acres. These birds might be said to guard their nesting territory throughout the year, although there seems to be no exhibition of this other than in the breeding season. The other males and females move southward for the winter, but are likely to return to their territory of the preceding season, which is then occupied for six or eight months. In the conduct of its nesting duties, the song sparrow apparently requires about two-thirds of an acre and does not usually occupy more during one nesting. In 1931, however, several banded males that returned to their territories, were observed to spread out to some extent and include larger areas in their domains. A reduced number of birds was the apparent answer

to this move rather than the existence of any special condition that made additional territory necessary. In no case was a male bird found mated with his partner of the preceding year.

The song sparrow is a home-lover and an individualist. Mrs. Nice concludes that it is "not over fond of flocking, even in the winter, and not of migrating en masse. The same bird may arrive at very different times in successive years, some of the females come before some of the males, and some of the adults come later than the juveniles."

Baldwin Bird Research Laboratory.—Detailed and extensive studies of the life history of the house wren (*Troglodytes aëdon*) (pl. 5) have been intimately associated with the Baldwin Bird Research Laboratory at Gates Mills, Ohio. Elaborate and highly technical apparatus has been developed to further the investigations and it is a fair statement that no other small bird has ever received the close attention that Doctor Baldwin and his associates have accorded this species.

Baldwin (1921) had already pointed out that house wrens not infrequently change mates between their first and second broods and, while of infrequent occurrence, had indicated that polygamy was not unknown. The species is unusually abundant in and around the Chagrin Valley, near which the laboratory is located, and many wrens have returned year after year to nest in the locality. Literally hundreds of young have been banded, but strangely enough very few of these have returned to breed in their natal areas. It is well known that juvenile mortality is very heavy, ornithologists generally accepting the theory that on an average each pair of adult passerine birds will raise but two nestlings to maturity. Nevertheless, since the different species remain practically numerically constant, it would seem that there must be a larger percentage of survival of the young than is indicated by the few return records of yearling birds.

In an effort to answer this question, an intensive study was made in 1926 and 1927. (Cf. Baldwin and Bowen, 1928.) A laboratory assistant was assigned to the task, and during the two seasons the entire wren population of this large area was under almost constant observation. Most of the nesting birds were repeatedly trapped and handled. While a few birds were captured that had been banded in previous seasons, in almost every instance the record showed that they were adult at the time of banding. The problem as to what becomes of the young birds is still one that challenges the efforts of the investigator.

In a study to determine the relation between the time that the adult wrens spend at their nesting activities and the time that they spend in seeking food and rest for themselves, Doctor Baldwin and

his assistants invoked the aid of thermoelectricity. (Cf. Baldwin and Kendeigh, 1927.) A thermocouple, made of copper and constantan, was installed in the nest, the thin, flexible wire passing just above the eggs with the junction of the two metals at the middle of the nest. Wires were carried from the thermocouple to a recording potentiometer in the laboratory. Here the recording pen rested on a strip of paper marked in degrees of temperature, and this paper was rolled past the pen at a constant speed. When the female was on the nest the thermocouple came in contact with her body, resulting in an electromotive force sufficient to move the pen in the potentiometer. In fact, so sensitive was this apparatus that a record was made on the moving paper every time the bird stood up and turned around in the nest.

During the summer of 1926 a record some 250 feet in length was obtained representing 91 days and nights. Four nests of the house wren and one of the robin received similar attention. As would be expected with these species the differentiation between the periods of attentiveness when the bird is actually on its nest, and the periods of inattentiveness, when feeding or resting, is best developed with the female, but nevertheless, the same relation applies also to the male.

In one case a female wren (71653) was found to incubate during the day for average periods of 14.3 minutes, alternated with 6-minute intervals when she was away feeding. During the incubation period she spent every night but one in the nest. On this one occasion she left her nest at 8.50 p. m. and did not return until 1.04 the next morning.

One more example, illustrating further the character of the researches conducted at the Baldwin laboratory, has to do with the temperature variation in young birds. (Cf. Kendeigh and Baldwin, 1928.) Again the house wren was the subject and mercury thermometers, and the thermocouple were employed to obtain the necessary data.

Among ornithologists it is now a well-known fact that while the average temperature of adult birds is relatively high there is some variation in this condition. In fact, differences in body temperature of 4° or 5° may occur within a very few minutes. Unusual excitement or merely the natural metabolism may be sufficient to effect these variations. The variable temperature of adult birds does not seem, however, to be in any way correlated with atmospheric temperature.

In the case of young birds (that is, nestlings), the situation is different. Their temperature is extremely variable and were they dependent upon their own resources they would be truly "cold-

blooded " or with a body temperature equal to the surrounding air. This explains why brooding of newly hatched birds by the parent is so necessary for their proper development. During its life in the nest, however, the fledgling evolves an efficient control system so that when it is ready for separation from parental care its body temperature is more nearly uniform.

The young bird accordingly may be considered as a cold-blooded organism that develops into one with warm blood. This fact is of significance as supporting evidence that the immediate preavian ancestors were cold-blooded, which, of course, fits in with the modern view of the reptilian ancestry of birds.

The O. L. Austin Ornithological Research Station.—This station, located at North Eastham, Cape Cod, Mass., was established as recently as 1930, but the research program already prepared should result in important contributions to our knowledge of North American birds. The director, Dr. Oliver L. Austin, sr., has assigned himself the task of ascertaining causes, symptomatology, and curability of the many diseases of birds. Already he has published (1931) a short paper based upon many dissections, from which he concludes that injuries resulting from their own activities or from violence from other organisms and forces are the principal causes of death in birds.

Introduced species.—Investigations of the Biological Survey through the banding method are confined to native birds although exceptions are made when some special study of an introduced species is contemplated.

The remarkable increase and spread of the European starling (*Sturnus vulgaris*), since its introduction in New York City in 1890 and 1891, has been watched with much apprehension by students of birds. Because of the obvious potentialities of this bird for good or bad, the Survey early authorized and urged its cooperators to band them at every opportunity. As a gross result many thousands are now wearing numbered bands. Centers of starling banding activity have been Washington, D. C., and Columbus, Ohio. During the winters of 1927–28 and 1928–29, the author in company with other Washington ornithologists conducted a banding campaign that resulted in the marking of more than 4,500 of these birds. The work was instituted under the direction of E. R. Kalmbach, of the Biological Survey, who (1932) has described how the banding operations so discouraged the birds that they have not since resorted in large numbers to the church towers where so many of their fellows were ignominiously treated.

About 125 of these birds have since been reported as returns. Seventy or more of these have been from points less than 20 miles

from the point of banding, 28 being recaptured during subsequent breeding seasons. It therefore appears, as Mr. Kalmbach has pointed out (loc. cit., p. 68), that "something more than 23 per cent of the wintering starlings of Washington were essentially resident birds." Determination of this fact is of much importance in planning control measures against the large winter roosts.

Another contingent apparently has developed or is developing migratory habits, as many of the Washington birds have been reported from northern points, mostly from Pennsylvania and New York. Recoveries at Wallingford, Vt., Cape Vincent, N. Y., and Cornwall and Elgin, Ontario, constitute the most northern points from which these birds have been recovered.

In subsequent winters a few returns were received from points as far south of Washington as southeastern Virginia. It is possible that these represent some of those that had developed the migratory habit, had nested north of Washington, and had merely gone on past the Capital when on their autumnal migration. Additional evidence of such a migratory flight is contained in the record of a starling (A200521) banded November 20, 1928, at Norristown, Pa. where it was apparently a winter resident, and recovered at Palatka, Fla., in December, 1930.

Long-range returns.—Banded birds recovered at long distances from the points of banding, are naturally of exceptional interest. Through the friendly cooperation of correspondents in many regions these records are increasing rapidly. Particularly is this true of South and Central American and Caribbean countries, while there are now three records of American banded birds (Arctic terns) that were recovered in the Old World.

The migration route of the Arctic tern (*Sterna paradisaea*) has long been one of the unsolved ornithological problems. Its breeding range is circumpolar, while in winter it has been found south to the Antarctic Continent. The problem has been to determine the path followed by those birds that breed in northeastern North America. Austin (1928) points out that while south of Long Island, N. Y., the species is practically unknown on the Atlantic coast of either North or South America, large numbers of these birds have been observed during the latter part of August, between Newfoundland and the Irish coast.

During the summers of 1927 and 1928 Doctor Austin was engaged in ornithological investigations on the coast of Labrador where he banded several hundred of these terns. One (548656), banded as a nestling in Turnevik Bay on July 22, 1927, was found dead near La Rochelle, Charente-Inferieure, on the west coast of France, on October 1, 1927. Another (548138), also banded as a chick on July

23, 1928, was picked up dead on the beach at Margate, 15 miles southwest of Port Shepstone, Natal, on the east coast of South Africa, on November 14, 1928. This last is the longest flight on record for any banded bird as the shortest possible distance from point of banding to point of recovery is 8,000 miles, while 9,000 miles is a conservative estimate for the entire flight, considering the course that the bird must have followed. For a bird not more than three months old, it is a truly remarkable journey. One other African return record is available: A tern (A. B. B. A. 1258), banded on July 3, 1913, at Eastern Egg Rock, Me., was found dead at the village of Ikibiri, South Nigeria, West Africa, in August, 1917. At the time of banding this bird was identified as the common tern (*Sterna hirundo*), but it is now believed that it was the Arctic species which does nest in small numbers on the New England coast. The chicks of the two species are much alike and even the adults might be confused.

In the light of these three records it now appears that the route of the Arctic tern from its breeding grounds in northeastern North America is eastward across the ocean, probably by way of the British Isles, to the coast of Europe, where, joining forces with those that breed in the northern part of that continent, they turn southward and follow the coasts of Europe and Africa to their winter quarters (fig. 3).

As above stated, it is now believed that there is no authentic record of a banded American common tern (*Sterna hirundo*) crossing the ocean. Nevertheless, there are many long range returns for this bird. Colonies in the Great Lakes and on the coast of New England have been the scene of much banding activity, and more than 80,000 have been banded. Two have been reported from Puerto Rico, 3 from eastern Mexico, 1 from the Republic of Haiti, 2 from the Dominican Republic, 1 from Panama, 7 from the island of Trinidad off the northern coast of South America, 3 from Venezuela, and 2 from the northeastern coast of Brazil.

A laughing gull (*Larus atricilla*) (A518811) banded at Muskeget Island, off the coast of Massachusetts, on July 13, 1930, was killed January 26, 1931, in Acajutla Bay, Salvador. This bird had not only flown more than 2,000 miles but it had crossed from the Atlantic coast to the Pacific coast.

Four Caspian terns (*Sterna caspia*) banded at their breeding colonies in northern Lake Michigan, have been reported more than 2,500 miles southeast, at the mouth of the Magdalena River, Colombia, while a fifth was recaptured at San Cristobal, Cuba.

A large colony of black-crowned night herons at Barnstable, Mass., was visited regularly for several seasons, and more than 2,500 were banded. (Cf. May, 1926.) From this work return records

were obtained from points to the north, west, and south, the most distant being a bird (233743) recovered on the Island of Jamaica,

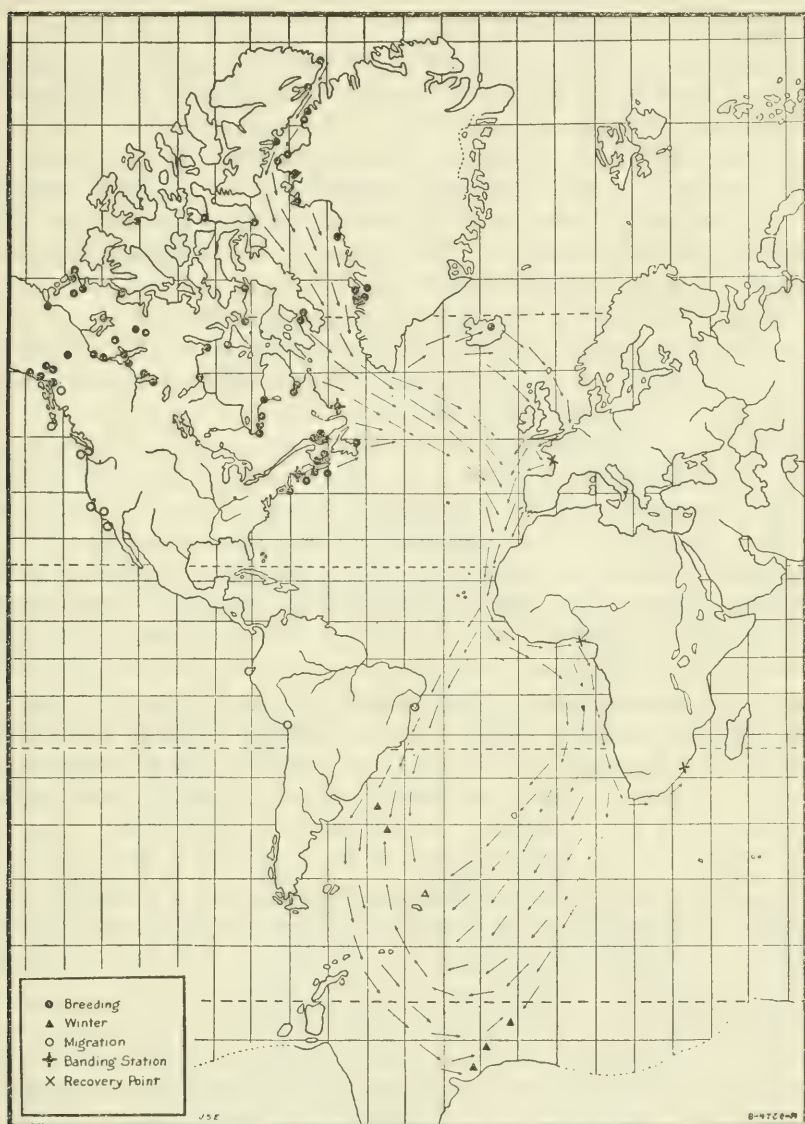


FIGURE 3.—Distribution and migration of the Arctic terns of eastern North America. Solid spots represent breeding colonies, those marked with crosses being banding localities; the crosses in France and Africa show points of recovery of banded birds; triangles show winter quarters; arrows indicate migration route as now understood

some 1,750 miles nearly due south of the point of banding. Another bird of this species (368306) banded at Indian Head, Sask., on

June 20, 1925, flew about 2,300 miles southeast to Alvarado, Vera Cruz, Mexico, where it was killed on November 15, 1925; while a third (A675440) made a trip of similar length and in the same direction, from Webster, S. Dak., to a point near Habana, Cuba.

The great blue heron (*Ardea herodias*) also makes long flights. Two of these birds banded at Waseca, in southeastern Minnesota, were recaptured almost due south in Central America. The first (334487) was taken 1,900 miles distant at El Hule, State of Oaxaca, southern Mexico, while the other (334402) was killed after a flight of 2,600 miles to Gatun Lake, Panama. Still a third bird of this species (204206), banded at Hat Island, in Green Bay, Wis., flew southeast nearly 1,700 miles to the southern coast of Cuba, its capture forming the first record for the race in that country.

A long-billed curlew (*Numenius americanus*) (531112) banded at Brigham City, Utah, flew southwest about 800 miles and was recaptured in northwestern lower California.

Among the ducks the pintails (*Dafila acuta*) and blue-winged teals (*Querquedula discors*) have made the longest flights. A pintail (367451) banded at Ellinwood, Kans., flew northwest more than 3,300 miles to the mouth of the Kobuk River, Alaska; another (227609) banded at Keno, Oreg., in September, was killed 2,800 miles to the southeast, near Belize, British Honduras; two others (A638860 and A647295), both banded on the same day, one at the Bear River Marshes in Utah, and the other at Dawson, N. Dak., were killed on the same day by the same man at Toluca, near Mexico City, Mexico. A blue-winged teal (A510183) banded at Ellinwood, Kans., flew 1,800 miles southeast to Corocito, Honduras, while another (531961), banded at the same place, traveled more to the eastward and was recaptured near Elia, Camaguey, Cuba. One of these little ducks (363850), banded at Kearney, Nebr., flew southeast about 2,600 miles to Santa Marta, Colombia, and another (4576), banded at Lake Scugog in southern Ontario, was recovered after a flight of about the same length, on the Island of Trinidad, off the north coast of South America.

Although not a large number of hawks have been banded, they have yielded several return records of unusual interest. Among these are a ferruginous rough-leg (*Buteo regalis*) (A709881), banded at Rosebud, Alta., and killed 1,700 miles south at Alpine, Tex.; a duck hawk (*Falco peregrinus*) (310753), banded at King's Point, Yukon Territory, was killed at Duchesne, Utah, more than 2,000 miles south; a red-tailed hawk (*Buteo borealis*) (655444), banded at Hepburn, Sask., flew south about 1,800 miles to Flatonia, Tex.; and a marsh hawk (*Circus hudsonius*) (A697063), banded at

Argusville, N. Dak., flew 1,100 miles in a southeasterly direction and was killed at Guantanamo, Cuba.

The number of small birds recovered after long flights is not so large, but considering the size of the birds, some of the distances traveled are none the less remarkable. For example, the family of sparrows and finches are not usually considered as birds of powerful flight, but a purple finch (*Carpodacus purpureus*) (A127258), banded at Hyde Park, Mass., was recaptured more than 1,400 miles to the southwest, at Nacogdoches, Tex., and another individual of this same species (77230), banded at Peterboro, N. H., flew nearly 1,500 miles to Thornton, Tex.

A tree sparrow (*Spizella arborea*) (38765), banded at Berlin, Mass., was recovered at Hardin, Tex.; a fox sparrow (*Passerella iliaca*) (643516), banded at Rhinebeck, N. Y., on March 18, 1929, was killed by a cat at Port au Port, Newfoundland, on April 30, 1929; a chipping sparrow (*Spizella passerina*) (C79688), banded at North Eastham, Mass., was recaptured at Grand Crossing, Fla.; a white-crowned sparrow (*Zonotrichia leucophrys*) (A196315), banded at Woodland, N. Y., was retaken at Moody, Tex.; a snow bunting (*Plectrophenax nivalis*) (C98323), banded at McMillan, Mich., on February 17, 1931, was killed by an Eskimo at Igdlorpait, Julianehaab District of southern Greenland, on March 30, 1931; a mourning dove (*Zenaidura macroura*) (306053), banded at Fort Riley, Kans., was killed at Apipilulco, State of Guerrero, Mexico; a catbird (*Dumetella carolinensis*) (392781), banded at Schoharie, N. Y., was recovered at Tela, Honduras; and a robin (*Turdus migratorius*) (273933), banded at Crystal Bay, Minn., was recaptured at Pachuca, State of Hidalgo, in southern Mexico.

CONCLUSION

Considering the material now assembled, it is proper to ask: Of what value are these data? The answer is, that for the first time in the history of ornithology there exists a mass of definite, precise information, obtained from living birds, which deals with the complicated movements of the individual birds that go to make up migration. Previously the study of this subject involved the use of data that were obviously incomplete, in most cases being little more than observations of the arrival and departure of the various species in different localities. The movements of the birds that make up the flocks could be only surmised, and the guess of one man was as good as that of another. Second, we are now rapidly accumulating a wealth of information showing how a bird develops, the transition of its plumages, its identification with the same or different mates in

successive seasons, its diseases, food preferences, and many other subjects that in the past could not be adequately studied or at best were but imperfectly known.

Not only does bird banding make it possible to make definite contributions to an increase of knowledge, but in some important instances the material is being applied to pertinent administrative and economic problems relating to our native birds.

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Photograph by Karl Christofferson

A COMBINATION TRAP BAITED WITH WATER DRIPPING FROM THE PAIL INTO A SHALLOW BASIN WHICH IS ALMOST CONCEALED BY THE LOWER DOOR

The doors are released simultaneously.



Photograph by M. J. Magee

1. AN EFFICIENT WARBLER TRAP SET OVER A DRINKING FOUNTAIN UNDER AN
APPLE TREE



2. TRAP HOLDING NEARLY 250 LESSER SCAUP DUCKS

Paul J. Rainey, Wild Life Refuge, near Abbeville, La.



1. TRAP HOLDING A LARGE CATCH OF DUCKS AND A FEW CANADA GEESSE
Lake Malheur bird reservation, Voltage, Oreg.



2. INLAND CREEPER TRAP

The collar of wire netting below the trap chamber encircles the tree trunk spirally.



A CATCH OF BLACK AND WHITE WARBLERS MADE WITH THE INLAND
CREEPER TRAP



BANDED HOUSE WREN

INSECT ENEMIES OF INSECTS AND THEIR RELATION TO AGRICULTURE

By CURTIS P. CLAUSEN

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Insects of various types play a very important rôle in affecting the production of practically all agricultural crops and products and have an important bearing upon the health of man and animals. Everyone is familiar with the common insects which each year attack garden and field crops. The aphids upon roses and other plants, the caterpillars and beetles which destroy the foliage of shade and fruit trees, not to mention the maggots and caterpillars in fruits and vegetables, daily come to our attention. Practically all of these which most frequently present themselves, whether as plant feeders, as burrowers in wood, or as destroyers of clothing, or which feed directly upon man himself, are injurious and troublesome, and in the public mind all insects consequently come under this classification. This condemnation, however, is entirely undeserved by a vast array of insect species which are entirely harmless in themselves, and at the same time are actively engaged in destroying the injurious species. That insects should prey upon one another is no more strange than that the larger animals should do so. The manner in which this is accomplished in the insect world, however, is much more diversified.

Under normal conditions in nature a state of equilibrium exists between all the elements which go to make up the plant and animal world. No one species attains a pronouncedly dominant position, and, on the other hand, the species which prey upon it do not increase to an abnormal extent. Various influences may disturb this balance from time to time, though these are only temporary and the normal condition is soon restored. The advent of man, however, has completely and permanently upset the equilibrium in large areas throughout the world. The elimination of the natural flora and the substitution in many localities of a single agricultural crop have been followed by very unexpected results. These vast areas of new vegetation made conditions ideal for the development of insects which feed upon these particular plants, and instead of

being merely elements in a stable complex these insects have assumed the status of a veritable plague and have persisted in destructive numbers year after year. This is the condition which we face constantly with practically all of our principal crops in this country. In those parts of the world where agricultural practices have been stabilized for several hundreds or thousands of years the injury is not nearly so great, owing to a partial restoration of the natural equilibrium.

Among the greatest influences which operate to maintain an equilibrium in the insect world and to restrain the destructive capacities of various species within reasonable bounds are those insects which attack others of their own class. With comparatively few exceptions, every insect has one or more species which feed upon it, and these in turn may be attacked by others. This adaptation in some cases is so exact that the parasite can live upon its single host species only, and the disappearance of that host consequently results in the extinction of the parasite. For this reason it is undesirable, from the point of view of the parasite itself, that the host should be unduly reduced in numbers. Under the condition of equilibrium there is a constant numerical rise and fall of the host species, which coincides with, or slightly precedes, the corresponding cycle of its parasites. In times of abundance of the host the conditions for increase of the parasites are at their best and consequently they increase rapidly. This results shortly in a decline of the host species. Eventually a point is reached where no further increase of the parasites is possible, and here the cycle starts once again. From our point of view the question of importance is whether this parasite attack keeps the pest at a sufficiently low level so that crops are not seriously damaged. Where the reduction is not sufficient, it is necessary to utilize mechanical control measures, such as spraying, dusting, and fumigation.

Within the United States probably more than half of our most destructive insect pests upon agricultural crops have been brought here from other parts of the world. Among these we might mention, as better-known examples, the cotton-boll weevil, the gipsy moth, the Hessian fly, the European corn borer, the Japanese beetle, the oriental fruit moth, practically all of the scale insects which are so destructive to citrus trees, and many others. In most cases these insects are of minor importance in their native habitats, whereas in this country the injury inflicted to crops is often very great. This greater destructiveness of introduced species may be due to several causes. Among them is the absence of the various natural enemies which assisted in holding the species in check in its native home. Usually when an insect gains entry into a new country it leaves its natural enemies behind, and consequently one of the important restraining influences upon it is lacking. There then ensues an ex-

uberance of development and increase greatly beyond anything known in its native home, and a species previously considered to be rather harmless looms up as a major crop pest.

There are wide differences in the habits of these insect parasites and predators. Some moths, for instance, are parasitic in the larval stage on adult cicadas and upon other insects of that order, while other species in the same stage may feed upon aphids or various scale insects. The two groups which dominate in the parasitic rôle are the wasps and flies. To most people, the fly is essentially a household pest, and they are not at all familiar with the very large number of species which live at the expense of other insects and are seldom seen.

There are many ways in which these parasites and predators live at the expense of other insects. Some feed exclusively upon the eggs, some feed upon the larvae or the pupae, or even upon the adult insects, while still others are parasitic, either externally or internally, upon the various stages. Those species which are true parasites live at the expense of a single individual throughout their period of development and consequently do not cause its death until their growth is completed. This may occur in different stages, dependent upon the species concerned. From the point of view of the parasite, this is of little consequence. From the viewpoint of the agriculturist, however, it is essential that the host be killed before it is able to reproduce itself, otherwise very little benefit will be derived by way of reduction in numbers of the following generations. It is for this reason that a 50 per cent parasitization, or even less, may result in the practical control of one pest, whereas 100 per cent may be of little value in the case of another. An instance of this is shown in the case of a small wasp, *Scutellista cyanea*, which attacks the black scale of citrus in California. The egg is deposited beneath the scale and the larva feeds upon the host eggs. The individual scale deposits from 1,000 to 2,000 eggs, and the parasite larva in the course of its development is able to consume only a portion of them. Those which remain are sufficient to maintain the infestation upon the trees at a maximum figure, and the presence of the parasite is consequently of little practical value.

Some species of insects are attacked by a very large series of parasites, in some instances numbering several dozen species. Where this occurs there may be extensive competition among them for the possession of the host. Where several species attack the same host individual, only one normally survives. This may be determined by an earlier time of the attack by the one species, or by a greater aggressiveness of its larva. In some species the newly hatched larvae are decidedly aggressive and have very pronounced cannibal-

istic tendencies, whereas others are very tolerant, and consequently are dominated and destroyed by the more active ones. Where two tolerant species occur together in the same host one or both may die from starvation, though occasionally it has been seen that both species develop and mature normally.

The rate of increase of insect parasites, or, rather, their capacity for reproduction, is dependent upon the manner of parasitization of the host and the hazards which are encountered during the period of development. Certain of these species may deposit 10,000 or more eggs and still show no increase in numbers from year to year. These species are the ones which do not lay their eggs directly upon or in the host, but instead scatter them promiscuously or place them only in the general vicinity of the host. The young larva then has the task of finding and entering its host, and the number which are able to do so is dependent upon the abundance of the latter. These minute larvae usually have a considerable power of search, though their range is limited. The larvae of *Perilampus*, which is one-twentieth of an inch in length, moves in a looping manner and the total distance it is able to travel during its life is consequently limited. The similar larvae of certain other wasps and flies are aided by an ability to jump considerable distances, and in this way they are often able to reach a host larva in their vicinity.

The ant parasites of the hymenopterous family Eucharidae, which develop upon pupae in the nest, deposit from 1,000 to 10,000 eggs and have a very unusual mode of life. In *Schizaspidia* the eggs are not laid in the nest at all, but are placed in large masses in the buds of trees. Here they pass the winter and hatch the following spring, shortly after the buds expand. At this time of the year the aphids are quite numerous on the foliage and the worker ants congregate about them to feed on the honeydew which they secrete. The young larvae of *Schizaspidia* are at this time resting on the leaves, and whenever opportunity offers attach themselves to the ants and are eventually carried down into the nest. Here they transfer to the mature larvae and eventually complete their development upon the pupae. In one single small mulberry tree which was examined, there were estimated to be at least 6,000,000 eggs of this species within the buds at the time of the examination. This proved to be a more or less constant condition each year. The ant population in the vicinity totaled only a few thousand, yet only about 50 per cent were destroyed by the parasite. The number of larvae which are able to attach themselves to the worker ants must be exceedingly small. They are entirely dependent upon the aphids to attract the ants to the tree, and if these aphids are scarce, then the chance of the parasite finally reaching an ant nest becomes exceedingly small, for only an occasional ant will be found upon the tree.

Another group of insects which presents a most unusual life history is the wasp family Trigonalidae. The species of this family are parasitic in fly pupae and in the larvae of other wasps. In most instances their effect is detrimental to vegetation, as the host species themselves are parasitic on various caterpillars which feed on the foliage. The female trigonalid deposits her very minute eggs upon the foliage of certain plants, and several thousand may be laid each day for a week or more. These eggs are eaten by the caterpillars as they feed on the foliage, and hatch within the digestive tract a very short time thereafter. The young larva then penetrates the intestinal wall of the caterpillar and enters the general body cavity. Here it searches about in an effort to find the larvae of some other parasitic wasp or fly. If successful in this search, it then enters the body of this larva in turn and eventually develops to maturity. In this instance the chance of a successful outcome is exceedingly remote, and consequently a very high potential rate of reproduction is necessary to maintain the species. The first great loss is suffered by the eggs themselves, as only a very small proportion of them will be eaten by caterpillars, and those which are not eaten never hatch. The eggs which are fortunate enough to be eaten, however, and which hatch within the caterpillar, are still confronted with the possibility that the caterpillar does not contain another parasite larva.

Where these insects occur as parasites of the nest-building wasps their life history appears to be even more complex. These wasps, of the genus *Vespa* and related forms, feed upon the body fluids of caterpillars and then return to the nest and feed their larvae with this material. With this host, the course of events in the life cycle of the trigonalid is as follows: The eggs are laid on foliage; they are eaten by the caterpillar and hatch in the digestive tract; the caterpillar is killed by a female *Vespa* and its body fluids, which contain the minute parasite larva, are consumed. The wasp then flies back to the nest and feeds this material to its own larvae, and thus the trigonalid finally reaches its ultimate host and eventually attains maturity.

It is quite clear, in view of the hazards which the trigonalid experiences before reaching its host, that a very great loss in numbers must take place. The production of 10,000 or more eggs by each female is very evidently a provision to compensate for this great chance of loss. Of this total, it is necessary for only 2 to attain maturity to maintain the species. That the egg production is not excessive in view of the mode of life is evidenced by the fact that this is one of the rarest of all parasite groups and few entomologists have ever seen a living specimen.

The rate of reproduction which has been mentioned in Schizaspidia and in the Trigonaliidae is not at all unusual and is equaled in many other groups, particularly among the parasitic flies, and also in some beetles. The greatest potential increase, however, is found in the relatively small groups of parasitic wasps of the families Encyrtidae and Platygasteridae which, among others, have developed the very remarkable habit of polyembryonic reproduction, where a single egg may give rise to a number of individuals. In some species this number is only 2, in others 12 to 16, and it may attain a total of several hundred or possibly thousands. From a single caterpillar as many as 3,500 of these minute wasps of the genus *Copidosoma* have been reared. The number of eggs required to provide for this total is not known, but it is quite certain that this one species, at least, is theoretically capable of increasing itself thousands of times each generation. As in the preceding cases, the capacity for reproduction is based on the limiting factors, and, as in the case of the Trigonaliidae, this group likewise is quite uncommon. These forms are seldom as important in the control of the host as are other parasites which have a very much lower reproductive capacity but which are free from these handicaps.

The rates of increase which have been mentioned may appear to be very high, and they are greatly in excess of that which is possible with the great majority of parasite species. It is of very little significance whether or not the parasite has a greater rate of increase than the host. The important point is whether it will continue to increase until the host species is overcome. Some parasite species have a considerable advantage in being able to produce several generations to each one of the host. These may all be passed upon the same host species or each one may be on a different host. This latter habit, however, may be a handicap rather than an advantage, as some one of these hosts may occur in only very small numbers and consequently increase upon it, or even the maintenance of its numerical status, is impossible.

In the case of those insects which have come to us from other parts of the world, it is desirable if possible to establish here the restraining influences which operate in their native homes. In other words, this is an effort to restore the natural equilibrium. We have no control over climatic conditions, and where this is the principal factor involved there is little hope of remedying the situation. If, however, the lack of its natural enemies has been responsible for the increase in numbers of a species, then we can import them and possibly reduce the pest to a position of minor importance.

The problem is oftentimes quite complex and the outcome of these importations can seldom or never be anticipated with confidence. A parasite which is very effective against its host in its native habitat

may not even maintain itself in the new locality, even though conditions are ideal for the host and very nearly duplicate those to which the parasite species has previously been accustomed. We are thus forced to adopt the empirical method and test all of the parasites in turn in the hope that some one or more of them will find the new environment favorable to its development and be able to subdue the pest.

The introduction of beneficial insects into the United States from other parts of the world is only one phase of the attempt to keep the injurious species sufficiently under control so that our various crops may be produced in sufficient volume and at a profit to the grower. The customary methods of control involve the application of various poisons which kill by contact or when eaten. In the citrus groves the great majority of pests are controlled by fumigation with hydrocyanic acid gas. Many of these control methods are very effective and the insect pests are kept at a very low level by their use. It is necessary, however, to employ this artificial control year after year, or several times each year, and consequently such work involves a constantly recurring expense, and one which the margin of profit on many crops does not justify. The control of the pest by the importation of insect parasites and predators, if it is successful, has this one great advantage: The initial cost is usually the total cost. For this reason a successful introduction may result in greatly reducing the damage and at the same time may render unnecessary any further annual expenditure. This complete control unfortunately is seldom effected, and in a great majority of cases we secure only partial success. The customary control by other means is still necessary, though possibly on a reduced scale.

The United States Department of Agriculture has been engaged for a great many years in the importation of the natural enemies of a considerable number of our principal crop pests. Rather curiously, the first attempt along this line, namely the introduction of the *Vedalia* beetle, was a complete success and served to focus attention upon the possibilities of this method of control.

The cottony-cushion scale became established upon citrus in California in 1872 and within 10 years was generally distributed throughout the State and seriously threatened the commercial production of citrus fruits. Entire orchards were being abandoned as unprofitable and the outlook was exceedingly gloomy. At this stage the department delegated one of its representatives to undertake the search for parasites and predators in Australia. This is the native home of the scale and consequently offered the best opportunity for finding its enemies. A short search revealed that the scale in Australia was kept in continued subjugation by a small beetle, *Vedalia cardinalis* by name. A quantity of these beetles were

collected and brought to California, and of these 129 arrived alive. These reproduced so rapidly that millions were available in a relatively short time. They were distributed throughout the groves in Southern California and in two years the menace of the cottony-cushion scale disappeared. To the present day there has been no serious outbreak of the scale in the State. Occasional small outbreaks do appear, but these are quickly found by the *Vedalia* and disappear within a few weeks or months.

This little *Vedalia* beetle has undoubtedly saved the growers of California millions of dollars each year, while the cost of importing it was only \$1,500. Since the time of the appearance of the cottony-cushion scale in California this scale has spread to various countries throughout the world, to Japan, Spain, France, Italy, Egypt, and practically every region in which citrus is grown. Into each of these countries in turn the *Vedalia* has been introduced and has repeated the success first achieved in California.

The striking results secured with *Vedalia* served as a stimulus to this type of work against many insects and in many countries. Similar world-wide distribution has taken place in the case of *Prospaltella*, which is a parasite of the scale insect *Diaspis pentagona*, found on peach and other fruit trees, and *Aphelinus mali*, parasitic in the woolly aphis upon apple trees. The success, however, has not been so uniform as was the case with *Vedalia*.

At the present time the importation of parasites and predators is one phase of the program for the control of practically all of our more important insect pests which have gained entry from other countries. For the last 25 years the natural enemies of the gipsy moth have been studied in various parts of Europe and Asia and a very large number of species have been shipped to the United States and tested. An extensive series of parasites has become well established and has had a very appreciable effect upon the moth infestation.

Another foreign insect which has become most destructive in this country is the so-called Japanese beetle, which was first found in New Jersey in 1916 and has since spread over a wide area. The search for the parasites of this beetle has been in progress for 13 years, and more than 1,000,000 parasites, of 24 species, have been imported from Japan, Chosen (Korea), China, and India.

The work to date upon this beetle illustrates very well the disappointments which are often experienced in parasite-introduction work. In northern Japan there was found a fly (*Centeter cinerea*) which in alternate years destroyed 90 per cent or more of all beetles in the field within two weeks after their emergence. From a study of conditions in northern Japan it seemed quite evident that the beetle was kept within reasonable bounds solely by this parasite, and

that without it considerable damage would have been done to various crops. This parasite seemed to be the solution of our problem here in the United States. It was capable of effecting a very high percentage of parasitization in the field, it destroyed the beetles before they were able to deposit their eggs, and, where the host population was reasonably uniform, it maintained a nearly constant status year after year. Centeter was shipped from Japan to the United States in large numbers and the first liberations were made in New Jersey about 10 years ago. It quickly became established and additional colonies from Japan have reinforced the original colonies each year. Yet the condition of the parasite infestation at the present time, 10 years after the first importation, reveals a very disappointing state of affairs. The fly has apparently reacted to the changed conditions in a different way from that of the beetle. In Japan the flies emerge each year shortly before the beetles and are present during the entire period of beetle emergence. Here in the United States, however, the flies emerge about one month in advance of the beetles and many die before they can find any of the beetles upon which to deposit their eggs. The remainder attack the first beetles which appear and all of them are dead before the peak of beetle emergence is reached. Owing to this failure to synchronize its time of appearance with that of the host, the parasite has not been able to increase its numbers. It is possible that this difficulty will adjust itself in time. With its present habits in the United States, however, the parasite can be of very little value in controlling this destructive beetle.

Probably the most extensive parasite-introduction project developed by the Bureau of Entomology is that upon the European corn borer, which is now widely distributed in the United States. Millions of parasites, representing a large number of species, have been imported from Europe and the Far East. Several species show considerable promise, though it is yet too early to estimate their value in reducing this pest.

The most recent work of the department along parasite-introduction lines has been that against the citrus black fly. This insect belongs in a family closely related to that of the scale insects. It is very minute, and develops in vast numbers on the leaves, often causing an almost complete loss of the crop. This black fly is a native of tropical Asia, but has become established in Cuba and other islands of the West Indies and in Central America. It does not occur as yet in the United States, but because of the wide variety of plants which it attacks and its very rapid spread, there is a real possibility that it will eventually reach the Gulf States. For this reason the department entered into a cooperative arrangement with the department of agriculture and commerce of Cuba for the importation of its natural enemies. Some years previous to this

time the Italian entomologist, Silvestri, had visited Malaya and reported finding several very effective parasites. These species were imported into Cuba during 1930 and 1931 and one of them, *Eretmocerus serius*, has been remarkably effective. The liberation of a few hundred individuals in an infested grove results in effective and complete control in 6 to 10 months. This parasite has been established in the other islands of the West Indies and in Central America, and in all localities has proved equally successful. As a result of this work, the citrus growers of the Gulf coast now have little to fear from the black fly. The possibility of its entry is greatly reduced, and should it appear in this country, the parasites can be quickly established here.

An equally successful result has recently been achieved in California in the effort by the college of agriculture and the experiment station to control the so-called citrophilus mealybug upon citrus. This species, like the cottony-cushion scale, evidently came originally from Australia. Its parasites were found and liberated in California, and within two years the pest was completely subjugated.

In Hawaii we find an exceptional illustration of the extent to which parasites may be utilized in controlling insects injurious to crops. The sugarcane growers in the islands maintain their own experiment station, which deals with all problems relating to sugar production. During the past 30 years at least five major insect pests of sugarcane have been effectively controlled by the introduction of parasites from various islands of the South Pacific and from Asia. In addition, the injuriousness of many other species has been markedly reduced.

The more frequent successes in Hawaii along this line as compared to those in the United States are due to several factors. The Hawaiian Islands are of volcanic origin and consequently all plant and animal life has been introduced. Their insect fauna is consequently quite simple, and the number of species is not great. There is less likelihood of the loss of an introduced parasite species through dispersion or by its transfer to another host. Climatic conditions are ideal throughout the year and are quite similar to those which exist in other Pacific islands. The introduced species consequently do not have to adapt themselves to a changed or a complex environment.

In many parts of the world an extended attempt is now being made to utilize these insect enemies of their own kind to prevent serious damage to agricultural crops. While they are often obscure, and their attack upon the plant-feeding species is seldom noticed by the grower, yet without them the economical production of practically all crops would be rendered much more difficult.

PLANT RECORDS OF THE ROCKS ¹

By A. C. SEWARD

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From an examination of the remains of plants preserved as fossils it is possible in some degree to reconstruct scenes from the remote past and to follow the changing vegetation on the earth's surface through many periods of geological history. Students of the history of the plant world turn to the records of the rocks in the hope of obtaining light on the origin and relationship of the various classes and groups represented in existing floras; their aim is to trace the development of the plant world through the ages, from the earliest age of which any records are available to the present day; to visualize the procession of floras "foreshortened in the tract of time."

The sources available to the botanical historian are the fossils preserved in the earth's crust, that is, the relatively thin film which is the only part of the earth accessible to human investigation. Rocks are in part consolidated gravels, sands, and muds upraised from ancient lakes and seas, sediments essentially similar to those now being carried by rivers and ocean currents and deposited in deltas, on sea beaches, and on the floors of shelving coasts. Other rocks are igneous in origin; some formed far below the surface under pressure and intense heat by the crystallization of molten magmas; others, such as lavas and layers of ash derived from volcanic sources and spread over the surface of the land or on the sea floor.

The present is the key to the past; a turbid river charged with sand and finer particles of clay carries to its delta, with these scouring from the rocks, floating stems and branches of trees which were growing on banks undermined by the stream; on its surface float twigs, leaves, and other wind-borne fragments. The sediment comes to rest as the velocity of the river is checked and in it are included samples of the contemporary vegetation. Forests growing near an active volcano are overwhelmed by lava streams or showers of ash, and it is not uncommon to find remains of plants of former ages preserved in material which caused their death.

¹ Sixth Hamilton lecture, illustrated by lantern slides, delivered at the Smithsonian Institution on Mar. 30, 1932.

It is easy to realize that the chances of preservation of plants is remote; we can picture low-lying ground covered with trees and smaller plants being flooded with water and ultimately buried under sand and mud; we can see rivers transporting logs of wood and broken foliage shoots, but conditions essential for preservation would seem to be fortunate accidents and of comparatively rare occurrence. We can not hope to recover from the rocks more than a few and usually fragmentary samples of plants which happened to be growing where it was possible for them to be saved from complete destruction.

The term "fossil" is often used in too narrow a sense; many people associate the expression "fossil plant" with wood that has been rendered indestructible by petrification, a common though unfortunately by no means the commonest method of preservation. A few examples will serve to illustrate the true nature of fossils, that is, plants or pieces of plants buried in the earth by natural causes.

At several places on the English coast, as on other coasts, there may be seen at low tide stumps of trees embedded in a peaty soil contrasted by its darker color from the sandy beach; the wood of the stumps is dark brown, though not much altered and easily cut with a sharp knife. With the stools and roots of the trees are associated leaves and seeds, and occasionally implements made by prehistoric man; in these submerged forests we have evidence of a sinking of the land surface at no very distant date. Another and more impressive illustration of the preservation of plants in places where they grew is furnished by seams of coal, especially by seams containing nodules of hard calcareous rock known as coal balls. Coal is usually described as the altered remains of the vegetation of swamps and lagoons. When a low-lying forest area was submerged and sediments were spread over the vegetable debris, it occasionally happened that water charged with mineral matter in solution, percolating through the covering sediment into the black mass of plant refuse below, deposited lime or other preservative substances in the cells and cell walls of the plant fragments and so converted into stone patches of the forest litter. Thin sections of the coal balls prepared by a cutting machine reveal on microscopical examination the minute structure of twigs, leaves, and seeds and enable us to reconstruct many of the plants which flourished in the Coal Age. The tissue and, in some instances, even the contents of the cells, are preserved in amazing perfection; as we examine under high magnification the minute cells we almost forget that we are looking at scraps of extinct plants which lived probably about 200,000,000 years ago.

Stems and branches of plants are occasionally found in beds of volcanic origin; in southern Scotland there is abundant evidence of vigorous volcanic activity in the early days of the Carboniferous

period; and in some of the beds of ash remarkably well-preserved stems of *Lepidodendron* have been found, a common tree in the later Paleozoic forests, which is distantly related to the living lycopods or club mosses, though probably not the direct ancestor of any surviving members of the great lycopod group. One specimen described several years ago will serve as an illustration: It is a block of stem about 1 foot in diameter encased in a shell of bark surrounding a mass of volcanic ash in which lies the woody axis of the plant. The more delicate tissues between the bark and woody cylinder have decayed, and their place has been taken by the ash. Both the stronger tissues of the bark and wood and the delicate tissue immediately surrounding the wood are almost perfectly preserved in siliceous material which, one imagines, the heated waters from some neighboring volcanic source deposited in the body of the fallen tree. Specimens of petrified wood, which are often found in beds of sandstone, have usually been transported a considerable distance from the place where the living trees stood. A piece of stem, which had no doubt been carried as driftwood far from its original home, was found by members of one of the British Antarctic expeditions in a boulder on one of the moraines of the Beardmore Glacier about 1,100 miles from the South Pole; its anatomical characters show that it was part of the stem of an extinct type of tree known as *Rhewoxylon*, which was first described from rocks of Triassic age in South Africa. It is clear that the occurrence of driftwood, whether fossil or recent, can not be trusted as evidence of the nature of the vegetation where the wood occurs.

The majority of fossil plants are not petrified but occur as thin films of carbonaceous matter on beds of shale; the internal structure is not preserved—only the outlines of cells and strips of the highly resistant superficial skin, or cuticle, which it is often possible to examine microscopically after treating the detached film with certain reagents. Some years ago small pieces of liverworts were discovered in England in a bed of carboniferous shale; they had been preserved as delicate mummified scraps from which it was possible to recognize the nature of the plants. These were the first recorded examples of Paleozoic liverworts, and it is noteworthy that in form and in the superficial cellular structure they agree very closely with certain living representatives of the group. Another common type of fossil is that known as a cast; in quarrying rocks stumps of trees, spreading at the base into long and forked rootlike branches, are sometimes laid bare. No trace of the original plant structure is left, merely a mass of sandstone or shale identical with the inclosing rock and preserving the form, occasionally also the external pattern, of the tree. One can picture broken stumps of forest trees

covered with sand, the wood and other tissues gradually decaying and crumbling into dust which was ultimately swept away by the flowing water; a mold or cavity was left where the remains of the tree had been. Subsequently more sand filled the space and thus casts of the tree bases and roots were made. Large casts of *Lepidodendron* stems illustrating this method of preservation were discovered many years ago in rocks of Carboniferous age near Glasgow in Scotland, and are now preserved as a natural monument.

One of the aims of geologists is to determine the relative ages of rocks by means of the order of superposition and the nature of the animal and plant fossils. It has been possible to arrange the rocks of the earth's crust in the order of their geologic age and thus to furnish what may be called a table of contents of the history of the world. The history of the earth, like the history of peoples, is conveniently divided into periods or chapters, and in recent years it has been possible to give estimates of the actual age in years of the several eras and periods represented by the sedimentary and igneous rocks. To the oldest known set of rocks the comprehensive term "pre-Cambrian" has been given; of the life of that era, which in duration probably equaled or even exceeded all the other eras and periods put together, we know practically nothing. It must have been in the course of this pre-Cambrian age that a lifeless world became the scene of the first act in the drama of life. Life probably began in the sea, but we can never expect to discover in the rocks traces of the inconceivably minute bodies of the first or the most primitive representatives of the organic world. From the rocks of the succeeding Cambrian, Ordovician, and Silurian periods several fossil seaweeds have been obtained; also, from Silurian rocks, a very few imperfectly preserved remains of terrestrial plants.

It is not until we pass to the sediments of the Devonian period that satisfactory records of land plants are available. Many years ago the late Sir William Dawson, of Montreal, described numerous Devonian plants from rocks of the Gaspé Peninsula, and much more recently there was discovered in Aberdeenshire, Scotland, at Rhynie, a bed of flinty rock, or chert, full of beautifully preserved petrified stems and spore cases of small plants which have added greatly to our knowledge of one of the most ancient floras in the world. The Rhynie chert may be described as a petrified sample of a peaty swamp. We can reconstruct a scene in Devonian Scotland: Pre-Cambrian mountains overlooking a flat expanse of swampy ground covered with a green carpet of plants a few inches high; not far away, we may suppose, were fumaroles providing heated water which dissolved silica from the rocks and subsequently deposited it in the tissues of the peat-forming plants. One of the

most abundant plants in the chert, appropriately named *Rhynia*, grew to a height of a few inches; its leafless cylindrical stems were borne on a creeping underground rhizome without roots, and some of the slender branches were crowned with cylindrical spore-capsules. Cross sections of the erect stems reveal an amazingly perfect preservation; a strand of comparatively thick-walled conducting tissue lies in the center of a mass of more delicate cells in which the remains of the living contents are clearly preserved in silica. *Rhynia* differs in some respects from all living plants; it is one of the simplest and most primitive of all known members of the vegetable kingdom which are provided with a conducting strand of woody tissue. With other Devonian types it has been assigned to a group known as the Psilophytales, which includes among other plants the genus *Psilophyton* described by Dawson and so named by him because of its resemblance in certain characters to the existing *Psilotum* of the southern Tropics.

Another of the Scottish plants, *Asteroxylon*, differed from *Rhynia* in having crowded scalelike leaves on the main stem and lower branches, while at the tips of more slender leafless branches were borne spore capsules. *Asteroxylon*, like *Rhynia*, was rootless. It was slightly larger; in its leafy stems and in the form of the conducting strand it is comparable to living species of *Lycopodium*. It is noteworthy that some of these Devonian plants resemble more than one type of living plants; *Rhynia* and *Asteroxylon* between them bear some resemblance to mosses, to *Psilotum*, and to *Lycopodium*; the spore capsules of *Asteroxylon* are not unlike those of some of the oldest known ferns. Thus we find in a single extinct plant or in closely allied plants points of contact with more than one living type; it would seem that such association in one individual of characters now distributed among different families or groups may be indicative of the common ancestry of plants that are now far apart. *Rhynia* and *Asteroxylon* are selected as examples of Devonian plants because of their exceptionally good state of preservation; we are able to picture them as living plants and to describe their minute structure with a completeness which makes it difficult for us to remember that they were members of a flora which existed about 300,000,000 years ago. Many other Devonian plants are known from North America, Norway, Scotland, Germany, and elsewhere, and it is possible to obtain a general impression of the outstanding features of a vegetation characteristic of the earlier stages of the Devonian period. The majority of the plants were leafless, or provided only with small appendages in place of the usual flat foliage leaves; some reached a length of several feet and in general plan of construction bore a certain resemblance to ferns, though true

ferns, so far as we know, did not play a part in the vegetation until later.

It is not intended to describe the oldest known terrestrial plants but rather to show by a few examples that, despite the meagerness of the records, it is possible to obtain a glimpse of the vegetation of the world in an age separated from the present by 200 to 300 millions of years. In the course of the latter part of the Devonian period many new types were evolved; woody trees vying in complexity of structure with modern conifers, though probably not closely related to them; plants bearing large fernlike fronds, which, it is suspected, were not true ferns but members of an extinct group, which rose to greater prominence in the forests of the coal age; trees with forked stems and branches bearing pendulous spore capsules and needlelike leaves resembling the *Lepidodendron* and other arborescent Lycopodialean plants of Carboniferous floras.

Passing to the Carboniferous period we find that the land vegetation had reached a much higher level; there were many new types, and the dominant groups were represented by an amazing variety of forms. It was in the latter part of the Carboniferous period that the Paleozoic plant world reached its culminating point. Attention is called to one of the extinct groups, the pteridosperms, so named because the large compound fronds closely resembled those of ferns but differed in bearing seeds and not merely spores. With them were associated some undoubted ferns, some of which differed widely from any that still exist; others already exhibited features characteristic of living ferns. The pteridosperms seem to have occupied a position in the late Paleozoic floras comparable to that now held by the flowering plants; it may be that these two great classes, though distinguished by several important features, are not unrelated. With the pteridosperms were associated tall calamites resembling in habit of growth gigantic *Equiseta*, though probably not their direct ancestors; *Lepidodendron*, *Sigillaria*, and other arborescent members of the group Lycopodiales, which includes also the living club mosses and ground pine (*Lycopodium*). In the forests of the Coal Age some of the more abundant and conspicuous trees seem to afford instances of gigantism; it is not clear that they left any direct descendants which persisted to later ages; they were highly differentiated plants which reached their maximum size in the latter part of the Carboniferous period and then gradually passed out of existence. Like the dinosaurs in the animal kingdom they were overdeveloped members of the plant kingdom unfitted to compete successfully with later and more efficient products of evolution. In the Carboniferous period there were also smaller, herbaceous lycopods surprisingly similar to living species of *Selaginella* which

furnish striking examples of persistence through the ages of certain plants that are relatively small and simple.

The study of extinct floras shows very clearly that while group after group were evolved, increased in numbers, spread over a large part of the world and then rapidly declined or died out, other products of evolution held their own with little or no essential change from the remote past to the present day.

At the close of the Carboniferous period the face of the earth changed; foldings of the crust brought into being mountain ranges; forests were replaced by the sparse vegetation of semiarid regions. This geological revolution had its repercussion in the course of organic evolution; the changed environment, which followed as the natural consequence of crustal changes, was a potent factor in altering the composition and the nature of the world's floras. Failure to discover undoubted pteridosperms in rocks formed subsequently to the Paleozoic era led to the belief that these seed-bearing fernlike plants failed to retain a hold on life in the altered circumstances caused by the revolution in the inorganic world. Evidence has recently been brought forward by Dr. Hamshaw Thomas and Dr. T. M. Harris, of Cambridge, definitely showing that some pteridosperms continued to play an important part in the vegetation of the earlier stages of the Mesozoic era. It was suggested by the writer several years ago that certain fernlike fronds that are abundant in Triassic and Jurassic floras might belong to pteridosperms; this opinion has now received some confirmation through the discovery of both male and female organs—pollensacs with pollen, and seeds—which undoubtedly belong to genera, e. g., *Lepidopteris*, which most paleobotanists had classed among the ferns.

Results obtained by students of fossil plants raise many problems other than those more directly connected with the great problem of evolution. We are accustomed to associate assemblages of living plants with different climatic conditions, and it has been said that the application of knowledge gained from the present enables us to use fossil plants as "thermometers of the ages." One example will serve to illustrate this aspect of paleobotany. The greater part of the island of Greenland is now buried deep under vast ice sheets; it is only on the narrow coastal fringe and on a few isolated peaks (Nunataks) protruding through the ice that plants are able to complete their life cycle in the extremely short Arctic summer. Except in the district near Cape Farewell there are no trees—only willows not more than about 3 feet high and a prostrate birch. The flora, excluding the lower plants, includes nearly 400 species of flowering plants, a few ferns and their allies; it is a typical Arctic flora with temperate associates. On the west coast of Greenland and on Disko

Island, approximately 1,200 miles from the North Pole, there are beds of sand and clay with bands of lignite which were deposited as sediment in a bay of the Cretaceous sea and subsequently upraised. In these rocks have been found many fossil plants which bear no resemblance and show only distant relationship to the components of the present flora. The commonest Cretaceous ferns are closely allied to species of the genus *Gleichenia* that is now widely spread in the southern Tropics and entirely unknown in Europe and in almost the whole of North America.

Trees were represented by several kinds of *Platanus* (the sycamore of North America; the planetree of England), a genus now living in eastern North America, in a narrower territory along the more southern part of the Pacific coast, in Greece and Asia Minor: by several different conifers, including one related to the redwoods of California and Oregon, another allied to the umbrella-pine of Japan. There were also magnolias, an *Artocarpus* closely resembling in leaf and inflorescence the tropical breadfruit tree, and trees bearing leaves hardly distinguishable from those of the maidenhair-tree (*Ginkgo biloba*) which, it is said, no longer occurs in a wild state. The Cretaceous flora of Greenland is made up of many different plants, several of them belonging to genera that are now represented by tropical, subtropical, or temperate species. Others are extinct genera. It would seem that we might reasonably conclude from the evidence of the fossils that Cretaceous Greenland enjoyed a subtropical climate. There are, however, serious objections to this inference: we are hardly at liberty to assume that extinct species—and all the Greenland plants are extinct species—lived under climatic conditions identical with or even very near to those required by their modern descendants. It is well known that some existing plants are tolerant of a wide range of temperature and other physical conditions, also that closely allied plants often live under very different conditions. Moreover, it is conceivable that in the course of ages genera and families of plants may have undergone a change in their constitution; plants that are now unable to endure an Arctic or a temperate climate may formerly have been less sensitive and hardier. May we not think of change in the adaptability of an organism as well as of change in structure acquired in the course of thousands, or it may be, millions of years?

It is possible by altering the distribution of land and water to change the direction of currents in the sea and air and thus modify the factors governing climate; but it is doubtful whether any such alteration could so far ameliorate the climate of an Arctic land as to fulfill the conditions which seem to be indicated by the Cretaceous flora. There are two possibilities: First, the assumption, and it is

only an assumption, that Wegener's hypothesis of continental drift expresses a truth—in other words, the land that is now Greenland may have been farther from the North Pole than it is now; second, as already suggested, it is arguable that the relation between living plants and climatic conditions should not be accepted as applicable to the plants of other genera and species which lived about a hundred million years ago. The Cretaceous flora of Greenland is one of many ancient floras which raise puzzling and fascinating problems by no means easy of solution.

Reference has been made to evidence furnished by fossil plants of the gradual rise to prominence in the Paleozoic era of groups of plants which after a time of vigorous development became almost or completely extinct; evolution of the plant kingdom was characterized by the rise and fall of dynasties that are no longer with us. The study of fossil plants also affords striking instances of the remote antiquity of some genera that are still in being. The maidenhair tree that is often seen in cultivation is the solitary survivor of a group which in all probability traces back its ancestry to the latter part of the Paleozoic era. In the early stages of the Mesozoic era, particularly in the latter part of the Triassic period and through the whole of the Jurassic period, the ginkgo group was represented by many different genera, all of which, with the exception of *Ginkgo*, have long been extinct. *Ginkgo biloba* was aptly styled by Darwin "a living fossil"; it is unquestionably one of the most ancient types in the world. It was once almost cosmopolitan in its geographical range and now it lives only where man has planted it.

A retrospect through the ages shows that there has been an evolution, an unfolding of innumerable structural forms, some more complex and larger than their nearest living relatives, destined to endure for a time, then to disappear. Evolution was not a simple uniform progression as was formerly believed. We are still unable confidently to picture the procession of classes, groups, and families through the hundreds of millions of years that have elapsed since the earth received on its surface the pioneers of the plant kingdom. Imperfect as the geologic record certainly is, we can hopefully look forward to learning more of the mysteries of evolution from the records of the rocks than from any other source. The records, though lamentably incomplete, are rich in treasures worthy of study. The unexplored material both in museums and in the rocks is enormous; the workers in this fruitful field are unfortunately very few.

CULTIVATING ALGAE FOR SCIENTIFIC RESEARCH¹

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[With 3 plates]

Carl von Nägeli, the old master of botany, once planted some slimy green spirogyra plants in three aquaria. Surprisingly, the plants in the aquarium first planted died immediately, those in the second aquarium lived longer, while those in the third aquarium flourished until the tank was a mass of green slime. Time and again the plants in the aquarium first planted died while others lived. What was the answer to this puzzling riddle? Could it be the fault of the algae plants, all of which were similar when placed in the three tanks? Or was it due to the water, all of which came from the same supply and was supposedly pure? Von Nägeli, after pondering for some time, found the answer. The water in the three aquaria was not the same. True, it all came from the same well, but the water for the first aquarium had rested for some time in lead pipes. It had also come in contact with the brass cock, and had had time to dissolve some metal. The water for the second aquarium contained the residue of that water which had been enclosed in the pipe. But the water for the third aquarium came streaming directly from the well and was in contact with the lead pipes and brass cock for such a short time that it dissolved practically no metal. To prove his theory, Von Nägeli dropped a copper twopenny piece in a liter glass container of water that was pure and free from any trace of metal. He let it stand for four days, then filled the aquarium with healthy green filaments of spirogyra. Within one minute all the algae had died.

In fact, copper has so toxic an effect on algae that it is a very simple matter to remove all the green slime from a large pond. One needs only to attach to a rowboat a bag of copper sulphate and then drag it through the pond several times.

¹ This paper was written while the author was engaged in research as a National Research Fellow in the biological sciences at the Smithsonian Institution.

Although we all dislike algae in our drinking water, they are of use to modern science. For algae, the tiny celled organisms that make up green pond scum, contain in each little cell some of the green pigment called chlorophyll. It is this pigment that is most essential to both the plant and the animal world. Not only the food which plants themselves use but the food of man and all other animals comes from plants. The manufacture of this food is made possible by the chlorophyll in the presence of light.

This green pigment is present in higher plants, for example in the leaves of the oak tree and lettuce, just as it is found in the algae which are lower plants. A small amount of it is contained in each little cell, millions of which constitute a leaf. All cells divide and redivide many times. In the leaf the cells remain united to increase the size of the leaf as a whole, but in the unicellular algae the cells are separate. Many algal cells are so tiny that one single cell filled with green chlorophyll can be distinguished only under a microscope.

Scientists in their search to discover the effect of light, temperature, humidity, nutrition, and poisons on plants and chlorophyll find that often a higher plant composed of millions of united cells presents complications that hinder research. Since physicists and biologists have cooperated to study the mechanism of the plant cell, very intricate and delicate pieces of apparatus have been devised. Cells combined in tissue do not always give a correct indication of the processes that take place in the growing plant, for no matter how carefully the tissue is removed from the plant, the cells are harmed and will not long continue to live. But a single-celled alga carries on all the life processes in its one cell, so that it can be moved from its normal habitat and placed in conditions for experimentation with the assurance that it is registering its reaction to them. The single cell has two other advantages. The less complicated the organism, the less individuality it presents; also, the smaller the organism, the greater the number of organisms on which observations can be based. Both these factors tend to reduce uncertainties due to individual differences.

When a drop of water from a pond green with slime is examined under the microscope it is astonishing to see that the drop is a tiny world in itself. For not only are bright green cells of algae present, but also star-shaped and moon-shaped diatoms, bright yellow and orange yeast cells, infinitesimally small bacteria moving so fast that the eye can scarcely perceive their shape, long blue-green ribbons of multicellular algae, and a tangle of fungous cells. There are animals, too—transparent paramoecia turning and twisting, and jelly-like amoebae flowing about, all trying to engulf the plant cells. The

same struggle for existence is taking place in the drop of water that occurs in our own world.

It is impossible to determine the reactions of an alga to external conditions such as nutrition, temperature, light, and humidity when it is growing in a culture with different algae or other organisms. For although the tares were allowed to grow with the wheat until the harvest, they undoubtedly harmed the crop by reducing the amount of nutrient and crowding out the less robust wheat plants. And when growing with other organisms, the alga chosen for study may fare as the seed that fell among the thorns. If a standard solid milieu or substratum is chosen on which each alga is grown separately, the alga can derive full benefit from the nutrient conditions, but if bacteria or yeasts are allowed to grow in a culture (the medium of nutrition for the development of an organism) with an alga, it is quite probable that they will act upon the nutrients so as either to stimulate or harm the growth of the alga. Fungi are the worst foes of pure cultures, for if once they enter the culture the alga is soon completely overgrown by them. As algae grow more slowly than fungi, bacteria, or yeast, they run a greater risk of contamination. Algal cells are often coated with bacteria. The culture medium must be as unfavorable as possible to the growth of both bacteria and fungi, yet so constituted that it will not injure the delicate algal cells. The most rigid care must be employed in the preparation of sterile culture media.

In the time of Kützing and Von Nägeli, who contributed largely to our early knowledge of algae, the boundaries between genus, species, and variety were not very clearly defined. Many of the lower forms of green algae such as *Chlorella*, *Protococcus*, *Cystococcus*, and *Chlamydomonas* are so similar when found growing together in a pond or a swamp that even with the aid of the highest power of the microscope it is practically impossible to distinguish between them. But when cells of each one of these forms are separated and grown on solid media of similar concentration of nutrients, the colonies that develop by a division of cells show striking dissimilarities. These differences may occur in color, size, shape, and consistency of the colony, which is composed of millions of similar cells of the same species and variety.

There have been three corresponding conflicts in the botany of lower plants; in fungi, in bacteria, and in algae. The same issue has been at stake in each one, which resulted in the adoption and development of a scientific method for the study of lower organisms—the pure culture method.

In algology, as in the fields of bacteriology and mycology, the classification of algae, bacteria, and fungi was originally based on

knowledge gained by direct observation. The need of isolation of a single individual for the study of its life history and independent reaction to such external conditions as light, temperature, humidity, and nutrition was very slowly realized by the algologists. Just as in bacteriology and mycology, polymorphism, the idea that lower forms of algae change into higher forms of algae during their development, caused confusion in efforts toward classification. For instance, the round cells of *Protococcus* were claimed to change into the long, slender, needlelike cells of *Raphidium* at some stage of their existence. *Pleurococcus*, a unicellular form, was even accused of disguising itself for some reason as *Stigeoclonium*, a multicellular branching filamentous form. In 1896 Klebs pointed out the fallacy of these classifications by indicating that if *Pleurococcus vulgaris* could change into a *Stigeoclonium*, it should be classified with the branched filamentous algae, but if as claimed, *Pleurococcus* were a degenerate form of a *Stigeoclonium*, the latter should be considered an independent unicellular alga. Klebs emphasized the necessity of direct observation of the alga growing in pure culture if the exact determination of its life cycle were to be ascertained.

Famintzin in 1871 was the first person to grow algae in water cultures. The work of Knop and Stohmann with phanerogams in inorganic salt solution as well as the experiments carried on by Pasteur and Rolin on lower fungi inspired him to place cells of an alga that he had selected for study in hanging drops of solutions of inorganic salts on a microscope slide. A solution that has proved admirably fitted in nutritive value to the growth of the algae is a modified Knop solution made up in the following proportions and then diluted to one-third:

Calcium nitrate.....	1.00 gram
Potassium chloride.....	0.25 do
Magnesium sulphate.....	0.25 do
Potassium acid phosphate.....	0.25 do
Distilled water	1 liter
Ferric chloride.....	a trace

If the algae are grown in cotton-stoppered glass flasks holding 100 or 200 cubic centimeters of this liquid solution, and at the same time on solid medium made by adding 2 per cent agar plus 2 per cent glucose to the mineral solution, an excellent idea can be formed of the behavior of the individual algae in solution as well as of the distinctive characteristics of each colony of algae on solid medium. As the immigrant placed for the first time in his new environment has the greatest difficulty in adjusting himself to the change in diet, so the alga reacts to a similar change. On solid media the colonies form disks that vary from green to bright orange in color, that are gelat-

inous, button-shaped, or irregular in numerous other ways. A designer could easily find original ideas for buttons or prints from these colonial formations of millions of cells of the same species. (See pl. 1.)

In the solid medium described above, mineral salts and sugar are not in equilibrium, consequently striking differences in the reactions of the different species of algae show up very clearly. The cells in the colonies differ somewhat from each other owing to the fact that the colonies are composed of all ages of cells; old ones that perhaps developed directly from the original inoculum beside new cells that resulted from division to-day or yesterday. The cells varying in age produce different excretions which modify their growth and development. The disks of cells, as a rule growing centrifugally, attain a size that varies with the different species, owing to the accumulation of excretions and the growing concentration of the medium caused by loss of water. Some species grow deep down into the agar medium, while in others the cells are piled upon each other to form little peaks, possibly because they are seeking better aeration.

Another method found to be valuable for comparative studies of algae makes use of porous clay cups. (See pl. 2.) As Livingston (1908) describes, the porous cup after being sterilized in the autoclave or steam pressure cooker is filled with the nutrient solution desired, stoppered with a perforated rubber stopper and connected by a tube through the latter with a flask of the solution placed at a lower level. It was found necessary to place the flask of solution connected with the porous cup of solution in the autoclave for a second sterilization. At the same time a glass jacket, larger by 2 centimeters in diameter than the porous cup, was sterilized in the autoclave. Immediately on opening the autoclave, the glass jacket was placed over the porous cup and stoppered with sterile cotton at the base of the rubber cork. The whole apparatus was then supported by a ringstand and allowed to cool. The jacket was removed long enough to allow the quick inoculation on the cup of several different algae. The differences in growth, color, and consistency of the algae for the nutrient solution used were plainly visible through the glass shell. Because of the careful sterilization and by keeping the cup closed inside the glass jacket, it was possible for the algae to grow vividly on the cup for a month's time without signs of contamination.

The first successful attempt at isolating and growing algae in pure culture that has been recorded in the literature was made by Beyerinck (1890). He boiled some ditch water with 10 per cent gelatin, allowed it to cool, and then mixed with it a drop of water containing numerous unicellular green algae. Small algal colonies

soon appeared on the gelatin, so that successful transfers of two species of algae, *Scenedesmus acutus* Meyen and *Chlorella vulgaris* Bey. were made to other media.

One of the earliest methods employed for isolating algae was to pour a drop of water containing the algal cell desired for study in a 20 per cent gelatin solution or a 1.5 per cent agar solution which had been slightly cooled but not sufficiently cooled for solidification in a petri dish. By growing the culture in north light and observing it day by day under the microscope, algal cells were soon seen to separate from the original colony. These cells could be removed with a loop of fine platinum wire and placed in a new plate of sterile media.

Krüger (1894), Tischutkin (1897), and Ward (1899) were among other early workers to obtain pure cultures of algae by plating in agar or gelatin. Chodat and his pupils (1902) isolated species by placing pieces of sterilized unglazed porcelain in contact with a mineral nutrient solution. Repeated transfers were made to fresh sterile plates until a pure culture was obtained. In cases where there were a few algal cells among numerous bacterial and fungous cells, they used a mineral nutrient solution that was favorable to the growth of the algae and unfavorable to other organisms.

Pringsheim (1926) advocates silica-gel plates for isolating different species. Van den Honert's (1930) modification of his formula is highly satisfactory. Water glass is diluted to a specific gravity of 1.08 by means of a hydrometer. Ten cubic centimeters of this fluid is added to 7 cubic centimeters of normal hydrochloric acid and quickly mixed. The mixture is poured into petri dishes, where it gelatinizes immediately. The plates should be washed in running tap water for one day to wash out any remaining hydrochloric acid, then washed with distilled water and covered with nutrient solution. After 24 hours, the nutrient salts having penetrated into the silica-gel, the remaining solution should be poured off. Place a drop of the water containing the alga in sterile solution and pour it over the silica-gel plate. After a few moments pour off the water. Within two weeks' time the green algal cells will appear growing on the silica-gel and they may then be transferred to other sterile plates, repeating until a pure culture is obtained. On these silica-gel plates there is an even smaller development of bacteria and fungi than on agar plates.

The method that produces the most satisfactory results is that of placing about 10 cubic centimeters of the pond water containing the cells in 100 cubic centimeters of the solution described above. After several days, 10 cubic centimeters of this solution may be placed in sterile solution. When this has been repeated several times, a drop of the latest inoculated solution may be grown on the agar medium.

It will be necessary to reinoculate subsequent agar plates before the pure culture of the alga is obtained. Often a year's time and endless patience are required before the pure culture is secured.

By the monoculture method, a single cell is selected from a drop of medium as it rests on the slide of the microscope. Refined technique is necessary to operate the micromanipulator which removes the cell and places it in sterile culture medium.

The great majority of the forms isolated in pure culture are unicellular green algae belonging to the *Protococcales*. Only a few multicellular or filamentous green algae, and some blue-green algae have been successfully isolated so that they will grow on culture media for any length of time.

A number of modern workers have found pure cultures of algae indispensable in their attempts to discover the effect of different mineral salts on the nutrition of the algae. The effect of light on algae is steadily growing to be an important field of investigation.

Chodat (1929), the Swiss algologist, with untiring zeal and boundless energy, has collected algae from the red snow at the summit of the Alps to the basin of the Rhone. From cascades, pools, lakes, and swamps, he has hunted the algae which form a part of his collection of over 400 varieties of algae in pure culture. He has ably demonstrated that in a population of algae that appear homogeneous from a morphological point of view there are many physiological and morphological races. Once selected, the descendants of a single cell may maintain themselves unaltered and constant for a great number of generations. He emphasizes that the evolutionary cycle and variation can not be studied in these forms without starting from a single cell.

Otto Warburg (1928), the German professor who was awarded the Nobel Prize in medicine for 1931, utilized pure cultures of *Chlorella vulgaris* and other closely related unicellular green algae for his work on photosynthesis and cellular respiration. The study of normal respiration can only be possible by avoiding any permanent injury to the cells. The unicellular green algae lend themselves admirably to this study as the mechanism of photosynthesis is complete in the tiny unicellular individual with its green chloroplasts. The work would be difficult and even impossible if not carried on in pure culture since the presence of bacteria or other organisms might modify or stimulate the physiological processes within the algal cell.

Robert Emerson (1929), an American student of Warburg, has done noteworthy work on the function of chlorophyll in photosynthesis in the algae.

Van den Honert (1930), of Holland, used the filamentous alga *Hormidium* in pure culture for intensive study of the assimilation velocity of carbon dioxide.

Here at the Smithsonian Institution we have a collection of numerous unicellular green algae in pure culture. In the Division of Radiation and Organisms we are using these algae for investigations relating to the effects of light of different intensities and different wave lengths. All the experiments are being carried on with the underlying purpose of making the work strictly quantitative. Up to this time, the lack of sufficient physical data has made the results of similar research doubtful and often impossible to repeat or corroborate. The use of delicate thermocouples makes possible exact measurement of the intensity of the light as it falls on the organisms. All the light filters used have been carefully measured for their specific transmissions and ingenious devices have been skillfully built for quantitative measurement of the growth and development of the green cells subjected to the various lights.

An algal spectrogram (pl. 3) showing the lethal action of ultra-violet light has been obtained by growing unicellular green algae in pure culture on an agar-coated plate. Similar plates were exposed to different regions of ultra-violet light in a large quartz spectrograph for periods of time varying from 6 minutes to 18 hours. In the regions of ultra-violet beyond 3022 Å., the approximate limit of ultra-violet irradiation in nature, the green algal cells were killed. Decolorized lines appeared on the green algal plate for the lines 3022, 2967, 2894, 2804, 2753, 2699, 2652, and 2536 Å. Wave lengths longer than 3022 Å., that is, wave lengths 3130, 3341, and 3650 Å., had no appreciable lethal effect on the algae. Yet by the thermocouple measurements a greater intensity of light was directed on the cultures at wave lengths 3130 and 3650 Å. Experiments are now being carried on with exposures of varying time and intensity to determine more completely the lethal effectiveness of the different wave lengths, also to investigate the possibility of a stimulative effect on the growth of the algae for small doses of the different wave lengths.

Another experiment has been designed for the simultaneous determination of the effect of four intensities of light on 18 different unicellular green algae growing for a month or more in exactly similar conditions of medium, temperature, and light. The different strains of algae vary as radically in their reaction to these external conditions as do other organisms under diversified environmental conditions. It was found that some varieties grow better at a low light intensity than at a high one; some like intermittent light better than continuous light. One variety refused to grow in any of the light intensities provided.

In a similar manner, one variety of algae is submitted to light of different wave lengths, in an effort to determine the optimum condition for the development and growth of the cells.

In this paper I have not attempted to mention all the scientists who have contributed to our present knowledge of algology. The student who has collected a bottle of pond water and is eager to classify its contents as he selects his algae for pure culture will find assistance and pleasure in the works of such men as Chodat (1913), Wolle (1887), Pascher (1927), West and Fritsch (1927), Wille (1897), Collins (1909), and many others.

Algae can be found growing everywhere, for they can exist under very varied temperature conditions. Ponds, lakes, rivers, waterfalls, bogs, rain pools, ditches, wet rocks, damp ground, tree trunks, and fence posts are some of the places where they may be observed. The infinite pains and boundless patience required to obtain an alga in pure culture are fully recompensed by the satisfaction of watching a beautiful green or orange button-shaped colony composed of millions of cells develop from one or a few cells whose presence in a drop of water could only be detected by the use of the microscope.

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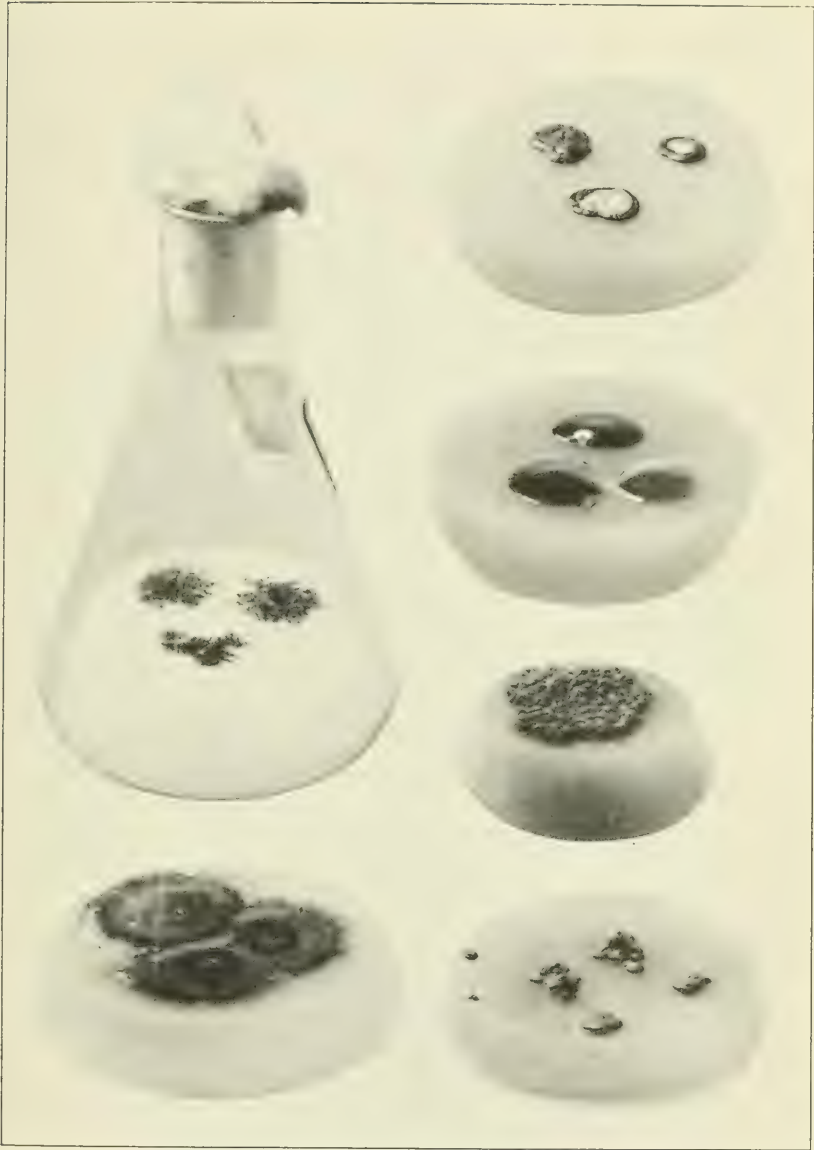
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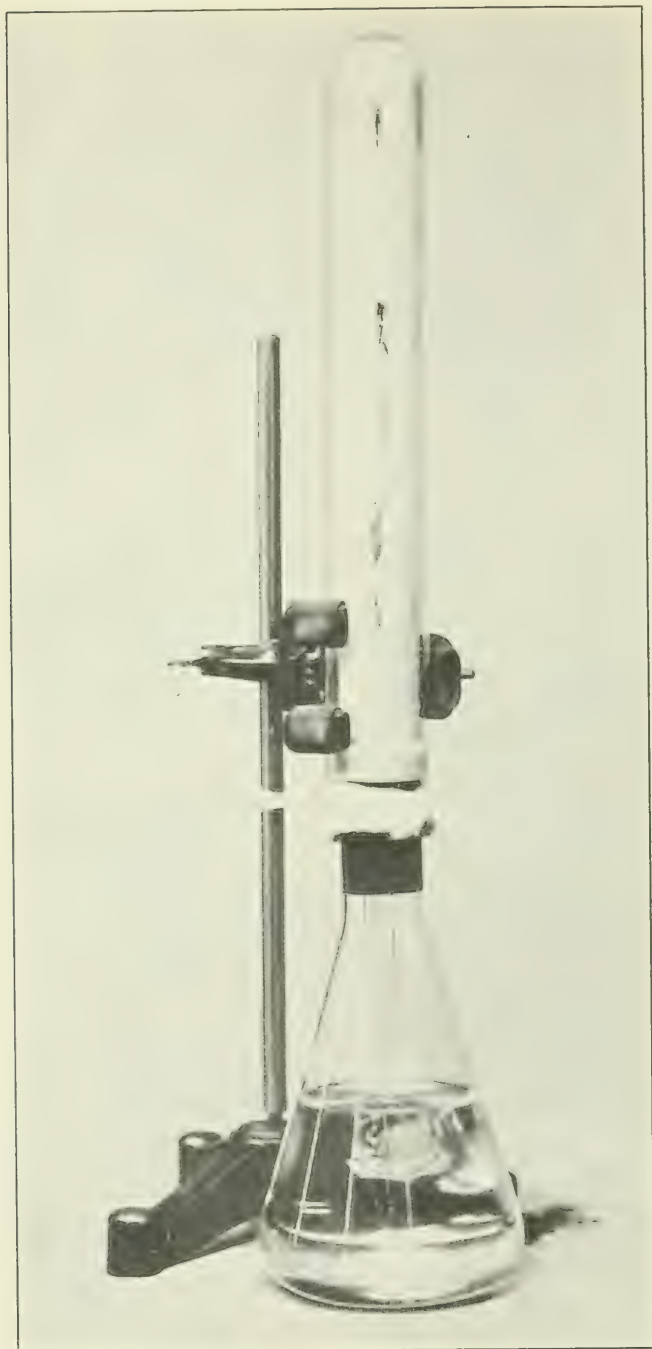
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PURE CULTURES OF SIX UNICELLULAR GREEN ALGAE GROWING ON AGAR



SIX VARIETIES OF ALGAE GROWING ON A POROUS CLAY CUP
INCLOSED IN A GLASS SHELL



ALGAL SPECTROGRAM SUPERIMPOSED ON MERCURY ARC SPECTRUM

The black regions between 2,536 and 3,022 Å. in the ultra-violet are the areas of dead and decolorized cells.

THE PRESENT STATUS OF LIGHT THERAPY ¹

SCIENTIFIC AND PRACTICAL ASPECTS

By EDGAR MAYER, M. D.

Saranac Lake, N. Y.

[With 1 plate]

Although there is much information concerning results of irradiating man and animals, explanations and indisputable generalizations are sadly lacking. When it is realized that even in photochemical reactions the physical process is not completely understood, the difficulty of explanation in biology and clinical medicine becomes more evident. No single explanatory hypothesis for the results ascribed to light action can yet be formulated, as there is great need of data obtained under definitely controlled conditions of dosage, intensity, and wave lengths in normal and in abnormal organisms.

There is a lack of agreement between the practical and therapeutic results and the scientific and experimental observations. Experiments have been carried out for the most part on healthy men and animals, whereas usually the practical results have been obtained on the sick. The abnormal organism is much more sensitive. Diseased tissue may vary from normal in sensitiveness to radiation. The animal skin is not perhaps comparable to the same organ in man (as, for example, in exposing shaved guinea pigs to sunlight, it is most difficult to produce erythema). In many reports the importance of sky radiation has been ignored, whereas it is possible that the beneficial effects of sunlight are in a great measure due to its luminous and infra-red portions.² It has been shown at Davos (Switzerland) that the radiation from the whole sky in summer has almost four times more ultra-violet shorter than the wave length 366 millimicrons than direct sunlight,³ and at Mount Wilson sky light was found to be several times richer in violet and ultra-violet than was direct sunlight.⁴ Hence, although the intrinsic brightness

¹ Reprinted by permission from The Journal of the American Medical Association, vol. 98, pp. 221-230, Jan. 16, 1932.

² Dorno, Carl, Studien über Luft und Licht im Hochgebirge, Brunswick, 1911.

³ Dorno, Carl, Physik der Sonnen- und Himmelstrahlung, Strahlentherapie, 1919.

⁴ Pettit, Edison, The Comparative Physical Properties of Sunlight and Light from Artificial Sources, Trans. 24th annual meeting, National Tuberculosis Association.

of a small area of the sky is much lower than direct sunlight, since the solid angle subtended by the whole visible sky is 92,000 times that subtended by the sun, the integrated amount of ultra-violet from the whole sky is very appreciable.

The sun, with its accompanying factors of environment, can hardly be compared to artificial sources of light. The exact physiologic effects of light or of the air bath alone are not clearly understood, nor is the effect of light on single cells. In application, dosage has been difficult to control, and marked variation in the effects comes from a small stimulative or a larger destructive dose of light. Similarly, the technic of application with most workers has been different. Published experiments lack specific details in many instances, especially those pertaining to the spectrum, such as its limits and the distribution and the character of the radiant energy employed. These must be defined accurately instead of attributing results merely to "ultra-violet energy." Perhaps this is the cause of the contradictory nature of many of the results published.

Many claims made for the use of radiation are still based on empiric results, and practical applications have been made without scientific support, chiefly because the action of radiation on the living cell is not clearly understood and the fundamental principles of the biophysics and physiology of radiant energy are still unsolved. Perhaps when monochromatic sources of ultra-violet energy in sufficient intensity have become available to repeat experiments, more exact information will be obtained. To name two specific reactions of exact wave lengths, one may cite the ordinary erythema or sunburn production and the direct production of antirachitic effect. Aside from these, despite claims, the exact wave lengths alleged to increase hemoglobin, prevent or cure the common cold, and cure forms of extrapulmonary tuberculosis, or even superficial ulcers, have not been established.

So it is evident that confusion must still exist. Controversies constantly take place between the proponents of the use of sunlight and those of artificial sources. The value of sunlight for one form of disease against another, for instance pulmonary tuberculosis as against the extrapulmonary forms, is a subject for debate. The advantages of different artificial sources of energy are still open questions. The workers in high altitudes are still enthusiastic in expounding their clinical results in contrast to those in the lowlands. This difference of opinion appears in part due to the fact that, in the development of the use of light for disease, only empiric results were known for many years before accepted laboratory evidence was produced which placed light therapy on a scientific basis. The broad scope, therefore, of this whole field will allow me only brief reference to such fundamental facts.

SOME PHYSICAL PROPERTIES OF LIGHT

Workers vary in their divisions of the ultra-violet into the near or long ultra-violet and the far or short ultra-violet. Clinicians for convenience often term those ultra-violets longer than 290 millimicrons (the lower limit of sunlight) as the near or long ultra-violets; while those shorter than 290 millimicrons are then called the far or short ultra-violets. This is the designation used in this article. The boundary line for physicists is often taken at 200 millimicrons because above this wave length it is possible to use ordinary photographic plates, quartz lenses and an apparatus open to the atmosphere. Below this limit, other means must be used. Some workers have even based the differentiation on transmission of the rays or the lack of transmission through window glass, the long or near ultra-violets penetrating window glass, the far or short being absorbed by it.

The spectrum of sunlight shows the visible region limited on one end by infra-red and on the other by ultra-violet rays (fig. 1). The visible spectrum extends from about 760 to about 390 millimicrons. The lower limit of the visible region may vary with different individuals according to the sensitivity of the retina. The ultra-violet rays of sunlight extend from about 390 to 290 millimicrons, and those of clinically used artificial sources from about 390 to below 200 millimicrons. The ultra-violet rays of a source such as the plain carbon arc of 20 amperes, which has been so frequently used clinically, extend to about 220 millimicrons (the intensity can vary with amperage and with impregnations in the carbons), while those of the quartz mercury-vapor arc terminate at 185 millimicrons.

All wave lengths of radiation appear to possess some ability to produce heat and to influence chemical reactions. As a rule, however, heat production is associated chiefly with the infra-red and the red rays. Light is associated with the rays from red to violet, while the most active rays chemically are the ultra-violet. The green region (500 millimicrons) is strongest in sunlight and best reflected by chlorophyll.

The infra-red rays longer than 1.4 microns are penetrating except for water, while the ultra-violet rays shorter than 0.3 micron are strongly absorbed.⁵ The regions of the spectrum vary greatly in their degree of absorption in different substances.⁶ Water and water vapor, for instance, absorb infra-red rays to a great extent except that region close to the visible from about 760 millimicrons to 1.4 microns. The ultra-violet rays lose the greater part of their intensity in penetrating the atmosphere to reach the lowlands.

⁵ Aschkinass, E., *Zeitschr. für Psychologie und Physiologie der Sinnesorgane*, vols. 11 and 12, p. 43, 1896. Vogt, A., *Schweiz. med. Wchnschr.*, vol. 55, p. 425, May 14, 1925.

⁶ Kimball, H. H., *Monthly Weather Rev.*, vol. 47, p. 769, 1919.

specimens, from 2 to 3 mm in thickness, transmitting as low as 80 per cent at 230 millimicrons. Ordinary window glass absorbs practically all ultra-violet radiations shorter than 320 millimicrons. Certain kinds of specially prepared glass transmit varying percentages of ultra-violet rays; clean vitaglass 2 mm in thickness, for example, transmits 75 per cent of the ultra-violet rays at 320, 25 per cent at 290, and about 5 per cent at 270 millimicrons. At normal incidence about 9 per cent of the energy between 700 and 400 millimicrons is lost on account of the reflection of light at the surfaces of the glass, increasing to 20 per cent for an angle of incidence of 60° .⁷ Most window glasses which are made especially for transmitting short wave length ultra-violet radiation season for the first few weeks of usage, losing a certain amount of transparency to ultra-violet. When this point is reached, the transmissibility is fixed and permanent, and they still transmit an effective quantity and quality of ultra-violet light for antirachitic effect. This has been shown for December in New York City with three hours' daily exposure in the middle of the day.⁸ Correx-D glass (Corning, N. Y., Glass Works) transmits the solar ultra-violet rays more fully than other glasses except quartz, but its cost still makes its use prohibitive for any but research purposes.

Various thin and porous cloths treated with thin films of paraffin, and wire mesh screens filled with celluloidinous material transmit the solar ultra-violet and visible radiations very well, especially when these materials are freshly prepared. The ultra-violet rays between 320 and 290 millimicrons are probably the best pigment-producing rays; because of their absorption by window glass it becomes difficult to tan behind such glass. Sand, snow, ice, and water increase the intensity of the ultra-violet by reflection; however, the dense humidity over bodies of water may intercept the reflected ultra-violet rays.

SOME BIOLOGIC EFFECTS OF LIGHT

Red and infra-red rays if of sufficient intensity produce an immediate hyperemia, which, however, soon disappears after the cessation of the irradiation. Infra-red rays longer than 1.4 microns, it has been shown, are more likely, through their superficial absorption, to produce cutaneous blisters in animals; those shorter than 1.4 microns penetrate the skin. The visible rays provoke vision, heat, and metabolic changes;⁹ the red rays are able to elevate subcutaneous temperature as much as 3° C. without causing bodily

⁷ Coblentz, W. W., and Stair, R., *Bur. Standards Journ. Res.*, vol. 3, p. 629, 1929.

⁸ Eddy, W. H., Report from Teachers College, Columbia University, New York City, Oct. 9, 1929. Eddy, W. H., *Science*, vol. 68, p. 13, 1928.

⁹ Sonne, Carl, *Arch. Physical Therapy*, vol. 10, p. 239, June, 1929.

fever. The infra-red and visible rays produce, through heating, a dilatation of superficial capillaries and an increased blood flow and exudation of lymph;¹⁰ but, apart from their heating effect, the rays do not destroy cells except when cells which have been sensitized by such substances as eosin and hematoporphyrin are exposed to visible rays.¹¹ Their heat effects may aid the action of the ultra-violet rays on body cells.

The heating effect of visible and near infra-red rays must be mild on account of the small absorption in the epidermis and the strong convection by the blood stream. The heat produced by the far infra-red is slowly conducted to the deeper layers and up to the surface and carried away by the blood stream and air. Temporary heat erythema is not strictly local, in contrast to the delayed erythema of sunburn, which is limited sharply to the exposed area, due to local tissue changes of the nature of degeneration of the prickle cell layer resulting in capillary stasis, diapedesis of leukocytes, and other signs of inflammation to the degree of blistering. Higher temperatures have produced increased oxygen consumption and greater local acidity of tissue, which can cause vascular dilatation.

Irritation of the skin gives rise to three responses; namely, local vasodilation, a wheal, and finally, under severe action, a local edema and blistering. This triple response, according to Lewis, is provoked directly by a substance (H) similar to, if not identical with, histamine. The primary effect of irradiation in producing evidences of inflammation has been concluded by some to be an injury to the capillary endothelium; by others this is considered secondary to irritation by the toxic products of prickle cell degeneration.

Blister production that results from great increase of permeability may serve a protective function, since the fluid absorbs greatly in the region of 280 millimicrons.¹²

Ultra-violet rays are rapidly absorbed, in most part, by tissues of a depth of less than 1 mm and produce marked chemical changes.

In penetrating through human skin visible and near infra-red rays are strongly absorbed by the blood of the corium and subcutaneous layers. The local heating effect is rather mild on account of the small absorption in the epidermis and the strong convection by the blood stream. The far infra-red has little penetrating power, most of it being absorbed in the epidermis.¹³ The heat produced is slowly conducted away by the blood stream and by air. Overex-

¹⁰ Hausmann, Walther, and Sonne, Carl, *Strahlentherapie*, vol. 25, p. 174, 1927.

¹¹ Hess, A. F., *The Ultra-violet Rays of the Sun*, *Journ. Amer. Med. Assoc.*, vol. 84, p. 1033, Apr. 4, 1925.

¹² Bachem and Reed, *Arch. Physical Therapy*, October, 1931, p. 581.

¹³ Miescher, G., *Strahlentherapie*, vol. 35, p. 403, 1930.

posure of the germinal layer may lead directly to blistering. There is greater variation in percentage penetration of ultra-violet than in other parts of the spectrum. At 280 millimicrons the absorption in the corneal and prickle cell layers is marked so that the great antirachitic effect of this wave length must occur in or about these layers; but on both sides of this band, around 300 millimicrons and 250 millimicrons, the penetration is greater, more radiation reaching the malpighian layer and corium, thus indicating that erythema production occurs in the germinal layer of the corium under the shadow of the upper layers. The corneal and granular layer, therefore, must play an important part in the light protection of these sensitive layers. From 250 millimicrons down the absorption in the corneal layer increases rapidly and at 200 millimicrons the absorption is so complete as to prevent any radiation from reaching the living layers of the skin.¹⁴

Grotthus' law states that a chemical reaction can not occur unless suitable radiations are absorbed. Hemoglobin absorbs ultra-violet rays as well as many of those of longer wave lengths up to approximately 450 millimicrons. Blood serum absorbs the ultra-violet rays, possibly chiefly because of its tyrosine and tryptophan content. The ultra-violet rays necessary for the prevention and healing of rickets and the production of erythema are those below the region of about 320 to 313 millimicrons.¹⁵ This region defines also the approximate upper limit of the bactericidal rays, although some experiments have shown bactericidal action with wave lengths at 365 millimicrons.¹⁶ Ultra-violet rays of sunlight extend in their lowest limit to 290 millimicrons,¹⁷ but lamps have some additional bands around 260 millimicrons that produce a fleeting erythema, as well as strong bactericidal rays at 265 millimicrons (fig. 2).

The brownian movement of protoplasmic colloidal particles ceases when exposure to ultra-violet rays coagulates the protoplasm.¹⁸ Egg and serum globulin have been said to be formed from albumin under ultra-violet irradiation. Lens albumin previously sensitized by certain salts, such as calcium, sodium, and magnesium, silicates, or

¹⁴ Bachem, A., and Reed, C. I., *Amer. Journ. Physiol.*, vol. 97, p. 86, April, 1931.

¹⁵ Sonne, Carl, and Rekling, Eigil, *Hospitaltid.*, vol. 70, p. 399, Apr. 28, 1927. Hess, A. F., and Weinstock, Mildred, *A Study of Light Waves in Their Relation to Rickets*, *Journ. Amer. Med. Assoc.*, vol. 80, p. 687, Mar. 10, 1923. Hess, A. F., and Anderson, W. T., *The Antirachitic Activity of Monochromatic and Regional Ultra-violet Radiations*, *idem*, vol. 89, p. 1222, Oct. 8, 1927.

¹⁶ Coblenz, W. W., and Fulton, H. R., *A Radiometric Investigation of the Germicidal Action of Ultra-violet*, *Amer. Journ. Electroth. & Radiol.*, vol. 43, p. 251, July, 1925.

¹⁷ Sheard, Charles, *Ultra-violet Radiation and Its Transmission by Various Substances*, *Journ. Amer. Med. Assoc.*, vol. 88, p. 1315, Apr. 23, 1927.

¹⁸ Burge, W. E., *Amer. Journ. Physiol.*, vol. 43, p. 429, June, 1917. Bovie, W. T., *Chem. Zeitg.*, vol. 37, p. 1486, 1913.

dextrose, becomes especially sensitive to ultra-violet radiation.¹⁹ Most bacteria are destroyed by rays of certain wave lengths less than 313 millimicrons, the bactericidal effect being in proportion to selective absorption.²⁰

Bactericidal action.—Ultra-violet rays impair the growth of pathogenic and nonpathogenic bacteria as well as destroy them.²¹ Young cultures have proved to be more sensitive to the rays than old ones. The resistance differs in bacterial individuals of the same culture and in various strains of homogeneous bacteria. The resistance also appears to be different in various bacterial species. Bacteriophages

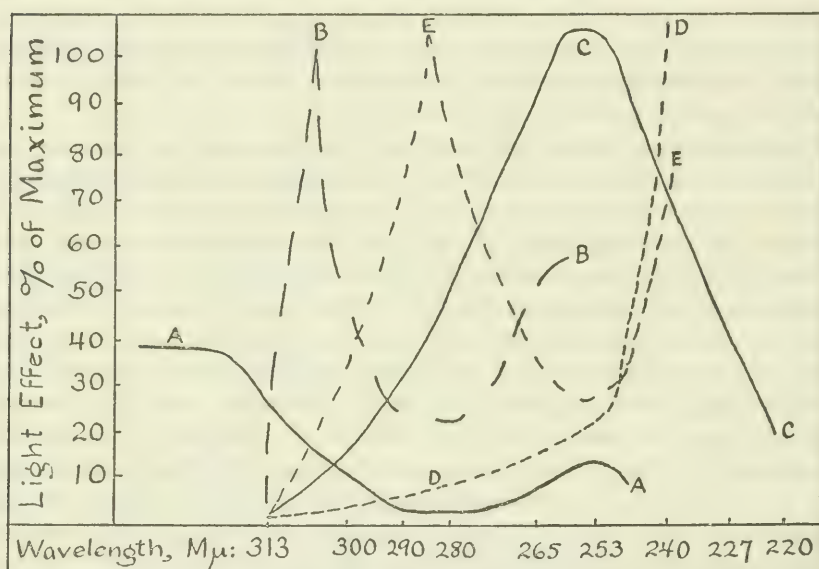


FIGURE 2.—Light effect in percentage of maximum effect: A, curve of skin penetration; B, curve of erythema (Hausser and Vable); C, curve of protein light reaction; D, curve of hemolysis; E, curve of paramécia (Sonne)

display a notable sensitiveness to the rays, but ferments resist the rays better. Bacteria, in dry and pulverized garden earth, have survived exposure to ultra-violet radiation. Ultra-violet rays may destroy bacilli on the skin without causing injury to the latter, this depending much on the individual and local resistance to the rays. The bactericidal action of ultra-violet rays on organisms present in the air can be shown.²²

¹⁹ Burge, W. E., Amer. Journ. Physiol., vol. 36, p. 21, 1915. Hinrichs, M. A., Proc. Soc. Exper. Biol. and Med., vol. 27, p. 535, March, 1930.

²⁰ Gates, F. L., Journ. Gen. Physiol., vol. 14, p. 31, September, 1930.

²¹ Stenstrom, Wilhelm, and Gaida, J. B., Proc. Soc. Exper. Biol. and Med., vol. 28, p. 898, June, 1931.

²² Winterstein, O., Strahlentherapie, vol. 39, p. 619, 1931.

The simple conclusion that the shorter the wave length of ultra-violet the greater the bactericidal action is in error, as it has been shown that there is a characteristic curve of bactericidal effectiveness for different bacteria, where the striking maximum is between 260 and 270 millimicrons.²⁰ The longer wave lengths limit of direct bactericidal action on *Staphylococcus aureus* was found to be between 303 and 313 millimicrons. Bactericidal action has been observed at 225 millimicrons. Polarizing of light has no demonstrable effect on this action. Temperature elevation usually increases the action. The hydrogen-ion concentration of the environment has no appreciable effect on the bactericidal reaction between limits of p_H 4.5 and 7.5.

The use of monochromatic radiation in experiments on paramecia and on certain bacteria has shown that the bactericidal action is probably due to a destruction of the protein molecules within the cell as well as to a lipid destruction of the surface membrane (fig. 2). Red blood cells in vitro are hemolysed by ultra-violet energy, possibly because of increased permeability of the cellular membrane or of the destruction of the cell stroma or of both.²³ Despite the statements of previous workers that the susceptibility of protoplasm to ultra-violet light is conditioned by the absorption of the toxic rays by the aromatic amino-acid radicals of the proteins, still the close reciprocal correspondence between the curve of bactericidal action and the curve of absorption of ultra-violet by the nuclein derivatives (cystine, thymine, and uracil) promotes the probability that a single reaction is involved in the lethal action of ultra-violet.

Protoplasm may be so affected by ultra-violet rays as to become especially sensitive to heat radiations.²⁴ The visible manifestations of tissue hyperemia due to ultra-violet radiation occur only after the lapse of a certain latent period, two hours or more. There probably takes place an absorption into the blood of products of tissue injury or an enhanced absorption of normal tissue products produced by such injury, with consequent erythema and edema. On repeated exposures, a pigment, melanin, is generally formed in the basal cells of the epidermis; this may be due to the action of certain skin oxidases on a breakdown product of tyrosine.²⁵

Unicellular organisms are stimulated to certain physiologic changes such as fission, or they are destroyed by ultra-violet radiation, depending on such factors as the intensity of the irradiation, its penetrative power and the size of the organism. Thus, ultra-violet rays may

²⁰ Harris and Hoyt, Science, vol. 46, p. 318, 1917.

²⁴ Bove, W. T., and Klein, A., Journ. Gen. Physiol., vol. 1, p. 331, January, 1919.

²⁵ Hinrichs, Marie A., Proc. Soc. Exper. Biol. and Med., vol. 26, p. 175, November, 1928.
Bove, W. T., and Hughes, O. M., Journ. Med. Research, vol. 39, p. 223, November, 1918.

reach the cell nucleus. Small doses of light appear to have a stimulating action, while large doses produce deferred physiologic changes, and still larger doses may destroy unicellular organisms. Amebas that are exposed to ultra-violet rays become strongly phagocyted by other nonirradiated amebas.²⁶

Melanophores in the scales of fish develop an increased irritability with a small amount of ultra-violet radiation, while with larger doses they develop a decreased irritability and eventually die. The contractions are similar to those of smooth muscle. It has been shown that an increase in tonus of involuntary muscle has taken place after irradiation with ultra-violet; likewise skeletal muscle shows an increase on such irradiation, these results running parallel to those obtained with melanophores. The contraction of muscles under ultra-violet appears to be due to changes in the muscle cell and not to nerve stimulation.

Cholesterol, a substance found in comparatively large quantities in the skin, is activated chemically by ultra-violet irradiation. This has been shown by isolating cholesterol and rendering it antirachitic by irradiation with ultra-violet rays. It becomes endowed with antirachitic power in an unknown way through the action of the ultra-violet energy. It has been recently shown that pure cholesterol can not be rendered antirachitic by the ultra-violet ray. The substance which is made antirachitic appears to be ergosterol, or an allied substance which is found in ordinary cholesterol as an impurity. Likewise, phytosterol of plants is so activated. Many food products, such as fats, oils, milk, vegetables and lettuce, may also become endowed with antirachitic power through exposure to sources of ultra-violet energy.²⁷ Ultra-violet irradiation of the pregnant mother renders her milk antirachitic.²⁸ How this takes place is still a matter of speculation; knowledge of the exact nature of radiation itself is so limited that its effects on tissues or food products becomes doubly difficult to understand. The greenness of many edible plants depends on several environmental factors, and sunlight in particular.²⁹ Vitamin A appears to be associated in some way with the greenness; that is, with the relative development of chlorophyll in the plant. Dry seeds and etiolated plants are as a rule poor sources of vitamin A. Mushrooms that thrive in darkness contain little of vitamin A.

²⁶ Mayer, Edgar, *Clinical Application of Sunlight and Artificial Radiation*, Baltimore, Williams & Wilkins Co., 1929.

²⁷ Sonne, Carl, *Arch. Physical Therapy*, vol. 10, p. 4, January, 1929. Hess, A. F., *Antirachitic Activity of Irradiated Cholesterol, Ergosterol and Allied Substances*, *Journ. Amer. Med. Assoc.*, vol. 89, p. 337, July 30, 1927. Steenbock, Harry, and Black, A., *Journ. Biol. Chem.*, vol. 61, p. 405, September, 1924.

²⁸ Hess, A. F., Weinstock, Mildred, and Sherman, E., *Journ. Biol. Chem.*, vol. 66, p. 145, November, 1925.

²⁹ Sherman, H. C., and Smith, S. L., *The Vitamins*, ed. 2, New York, Chemical Catalog Co., 1931.

FURTHER PHYSIOLOGIC EFFECTS OF LIGHT

The increase in calcium and phosphorus content of the blood serum in rickets and tetany under ultra-violet radiation is due in all probability to an increased absorption of calcium from the intestine.³⁰

Antirachitic or calcium-depositing agents, namely, vitamin D and ultra-violet rays of sunlight and of artificial sources, increase the free acid of the gastric contents, resulting in an increase in duodenal acidity. This aids in holding calcium salts in solution with the consequent increase in calcium absorption. Also, phosphorus absorption is increased, since calcium is usually associated in the body with phosphorus in the form of phosphates. Sometimes phosphorus absorption may be the primary effect.

Under solar radiation, the blood shows increased alkalinity, a fact attributed more to the action of the heat rays.³¹

Radiation with massive exposures from carbon and mercury arcs has increased persistently red blood cells and reticulocytes,³² but, contrary to expectation, there was no great influence exerted in hemoglobin regeneration in severe secondary anemia produced by continual bleeding of animals. Increase of hemoglobin in human anemias has been reported. However, this work does not yet convince us without much further support that such radiation is beneficial clinically in cases of anemia.

Reticulocytes vary in number with the season, being highest in the spring and lowest in the winter. This seasonal variation seems to be in direct proportion to the amount of sunshine. There may be a relation between the cure and the prevention of anemia, and sunlight or ultra-violet.³³ It is interesting to note that Macht found the serum of an individual suffering from pernicious anemia toxic to plant seedlings, this property being absent in specimens of blood from those with secondary anemia or other blood diseases. When the serum of a patient with pernicious anemia is irradiated with ultra-violet, it becomes much less toxic. These observations are in accord with those of some workers of a particularly favorable response of some patients with pernicious anemia to artificial sources of light.

Lymphocytosis in rabbits and possibly in man can be produced by exposure to the shorter ultra-violet rays.³⁴ Hematoporphyrin

³⁰ Abrahamson, E. M., and Miller, E. G., *Proc. Soc. Exper. Biol. and Med.*, vol. 22, p. 438, 1925.

³¹ See footnote 26.

³² Laurens, Henry, and Mayerson, H. S., *Journ. Nutrition*, vol. 3, p. 465, March, 1931.

³³ Macht, D. I., and Anderson, W. T., jr. *Journ. Pharmacol. and Exper. Therap.* vol. 34, p. 365, December, 1928.

³⁴ Clark, Janet H., *Amer. Journ. Hyg.*, vol. 1, p. 39, January, 1921. Hardy, M., and Chapman, J., *Amer. Journ. Hyg.*, vol. 10, p. 655, November, 1929. Spence, K., and Griffith, H. D., Report of the Medical Officer of the City of Aberdeen, p. 48, 1927.

injected subcutaneously or applied locally to the mesentery of a frog or a mouse sensitizes the vessels to the visible rays, capillary stasis is produced, and thrombi of leukocytes are formed in the vessels at different points along the endothelial wall. Eosin (1:1,000) sensitizes the capillaries to the visible rays, so that stasis is produced by these rays alone. Cell membranes and capillaries develop increased permeability on exposure to ultra-violet rays. Animals kept in darkness from birth can show growth changes differing in no way from those exposed to light, but blood examinations have in some experiments shown lowered blood platelets.³⁵ On exposure of these animals to quartz mercury vapor arc radiations, the number of platelets has rapidly increased to normal. There is also evidence that the coagulation time is decreased.

Basal metabolism is increased only slightly, if at all, by light exposures alone, but it can be markedly increased by exposure to moving air. Some workers have reported even a drop in many cases. Increased heat output by radiation under a provoked hyperemia demands increased metabolism. Increased mineral metabolism is definitely provoked by light alone to give increased urinary output of nitrogen, phosphorus, sulphur and chlorides. Following exposure to light, respiration is decreased in rate but increased in depth. Increased body heat production obviously demands accelerated vital reactions. The rate of growth may be increased under the action of light.³⁶

The improved physiologic action of the skin on exposure to light may be presumed; namely, as to increased secretory and protective powers. It may be speculated that the skin metabolism may be stimulated by light and the formation of glutathione may be increased. Perhaps the specific carbohydrate metabolism of the skin which has been demonstrated experimentally by the presence of lactic acid may likewise be stimulated.³⁷ This conception of the skin as an organ intimately concerned with complex chemical processes presents increased importance to the possibilities of light therapy. It has been related how intimately the skin is concerned with the elaboration of lipoid substances and how the epithelium

³⁵ Gunn, F. D., *Proc. Soc. Exper. Biol. and Med.*, vol. 24, p. 120, November, 1926. Sooy, J. W., and Moise, T. S., *Treatment of Idiopathic Purpura Hemorrhagica*, *Journ. Amer. Med. Assoc.*, vol. 87, p. 94, July 10, 1926.

³⁶ Goldblatt, H., and Soames, K. M., *The Effect of Radiation with the Mercury Vapor Quartz Lamp on the Growth of Rats Fed on a Diet Deficient in the Fat-Soluble Growth-Promoting Factor*, *Lancet*, vol. 2, p. 1321, December 23, 1922. Hume, E. M., *The Effect of Radiation with the Mercury Vapor Quartz Lamp on the Growth of Rats Fed on a Diet Deficient in Vitamin A*, *idem.*, p. 1318. Goodale, H. D., *Amer. Journ. Physiol.*, vol. 79, p. 44, December, 1926. Higgins, G. M., and Sheard, Charles, *Journ. Exper. Zool.*, vol. 46, p. 333, 1926.

³⁷ Pillsbury, D. M., *The Intrinsic Carbohydrate Metabolism of the Skin*, *Journ. Amer. Med. Assoc.*, vol. 96, p. 426, Jan. 7, 1931.

is a structure that actively functions in the elaboration of keratin from keratohyalin, and so ultimate explanations may be had as to the effect of light in overcoming derangements from the normal in metabolism.

Acne vulgaris is less common in tanned skin than in untanned skin. During an epidemic of chicken pox at Rollier's clinic, cutaneous vesicles were not found on tanned skin, whereas they did appear on unexposed areas beneath plaster casts. Erythema of the skin produced either by heat or by actinic radiations is accompanied by transitory increased bacteriophagic and bacteriolytic power of the blood serum and leukocytes for streptococci, pneumococci, and staphylococci.³⁸ Following exposures to solar radiations and to artificial sources of light, especially with combined exposures to moving air, remarkable muscular tonus has been produced in unused muscles, despite prolonged application of immobilizing casts.

It is doubtful whether systemic effects resulting from local skin irradiation are due to reflexes arising from stimulation of nerve end-organs. No specialized receptors for ultra-violet rays have been differentiated. Also the vasomotor reactions result just as readily when denervated cutaneous areas are exposed to light.

It is still debatable whether changes are produced in the blood directly by penetrating rays. If so the visible and near ultra-violet are responsible for systemic effects due to blood changes.

It seems possible that hormones are produced in the skin because a systemic effect, like the antirachitic, results from irradiation with rays of which only approximately 10 per cent penetrate to the blood vessels.³⁹

The action of light on the body is in all probability largely an indirect one by way of the cutaneous cells, nerves, and blood vessels. Ultra-violet rays for the most part are absorbed by the epidermis. Deeper penetration of the longer visible rays and of the shorter infra-red rays may allow of some slight direct action, but there is little cause to believe that this can be of much direct therapeutic value. Therefore, penetration should not be stressed as the factor for the interpretation of physiologic effects.

Heat rays and heat effects of luminous rays have been shown to increase and hasten the effect of ultra-violet energy, but also experiments⁴⁰ have shown that red rays may act antagonistically to ultra-violet. Thus cholesterol has become activated by ultra-violet rays so as to contain the antirachitic vitamin; thereupon a successive ex-

³⁸ Eidinon, A., Brit. Journ. Radiology, vol. 31, p. 35, January, 1926.

³⁹ See footnote 12.

⁴⁰ Bovie and Klein (footnote 24). Clausen, Ethel M. L., Proc. Soc. Exper. Biol. and Med., vol. 26, p. 77, November, 1928. Peck, J. L., Physiol. Abstr., vol. 10, p. 374, 1925.

posture to red rays caused a loss of antirachitic property. Likewise, old, ineffective ergot preparations could be reactivated on exposure to ultra-violet, but subsequent irradiation with red rays again destroyed the efficacy. On the other hand, the estrus hormone could be destroyed by ultra-violet but reactivated by red rays.

In short, a summation of the mode of action of light in the present state of our knowledge is difficult. The isolated experiments carried out on single cells, on bacteria, on the components of cellular structure, and so on, are difficult to carry over and apply to the effects on the human body. Certain rays do penetrate directly to the capillaries, but their effects can only be assumed through such action. Vitamin D-like substances are definitely formed, but their effects on the body, except in disturbances of calcium metabolism, are undefined. Increased cell permeability as a result of light exposure can be demonstrated, which may imply improved cellular nutrition. Exact effects on the other components of the skin and on the various skin functions, or directly on the blood circulation and so on the body functions, must still remain for future investigation to define accurately.

LIGHT AND MOVING AIR FROM OUTDOORS

The application of light necessarily requires consideration of accompanying moving and open air. With lamps, moving air from outdoors should be employed if possible. Air movement produces increased heat radiation and conduction with better respiration and excretory function of the skin. Cool moving air acts directly on the vasomotor system, stimulating the superficial capillaries, producing a hyperemia and, in turn, a depletion of the cutaneous circulation. This, acting as a massage, may be responsible for the development of muscle, otherwise immobilized in treatment. With sunlight therapy the effect of moving open air is greater, but air exposures may well be utilized with artificial light therapy through satisfactory ventilation of the treatment room. Carbon arc lamps may be effectively used outdoors in cloudy, warm weather. However, chilling should always be avoided, even at the expense of losing the air movement when one is employing artificial sources of light.

SUNLIGHT VERSUS CARBON ARC AND QUARTZ MERCURY VAPOR ARC LAMP

In mid latitude, sea-level stations, during midsummer, clear mid-day sunlight contains intense ultra-violet rays down to 297 millimicrons. Those around 290 millimicrons, its lowest limit, are in intensity about one-millionth of those around 310 millimicrons. Its emission of visible and infra-red energy is very high.

Proponents of solar therapy have insisted on the use of radiation having a spectrum with components relatively like those of sun-

light. The clinical results with solar exposures have been most favorable in the hands of these workers. Sunlight possesses an advantage in the favorable psychic reaction which makes the patients much more willing to submit to prolonged periods of exposure. Yet there is empiric evidence and theoretical basis for expecting very favorable therapeutic results with other combinations of light rays.⁴¹ Aside from the calcium-deficiency diseases such as rickets and tetany, the favorable clinical results with radiation can not be ascribed only to the vital ultra-violet region. In fact, even in bone and joint tuberculosis there is now impressive evidence indicating the importance of the visible radiation and the wave-length region lying between 320 and 390 millimicrons.⁴²

Quartz mercury vapor arc light.—About 0.1 per cent of the total output of the energy of sunlight is in the short wave length ultra-violet rays, the variation dependent on the geographic location, season of year, time of day, and kind of weather; but the total output of the solar "near ultra-violet" is large when one considers the total intensity of sunlight.⁴³ As against the mercury arc, it lacks the short ultra-violet rays below 290 millimicrons. The quartz mercury vapor arc lamp emits a marked preponderance of ultra-violet energy in relation to its total output. It emits relatively much less visible and infra-red energy than does sunlight; most of the infra-red comes from the heated quartz, the electrodes, the supports, and the reflecting hood.⁴⁴ About 17 per cent of its ultra-violet rays (the total ultra-violet being considered 100 per cent) are of shorter wave lengths than the lower limit of sunlight. The lower limit of its radiation is 185 millimicrons, but in therapy it is rarely below 200 millimicrons. Its upper limit of radiation is about 12 microns in the infra-red. The radiation less than 450 millimicrons represents two-thirds of all radiation below 1.4 microns. It consists of a weak continuous spectrum down to 250 millimicrons and a number of spectral lines of high intensity from 450 to 185 millimicrons. Quartz allows the transmission of the rays from 185 to 320 millimicrons which are not transmitted by window glass. The intensity increases rapidly in the first few minutes to reach the final value in

⁴¹ Maughan, G. H., *Amer. Journ. Physiol.*, vol. 87, p. 381, December, 1928. Sonne, Carl, *Arch. Physical Therapy*, vol. 10, p. 139, April, 1929. Reerink, E. H., and Wijk, A. V., *Biochem. Journ.*, vol. 23, p. 1294, 1928. Steenbock and Black (footnote 27). Hess, A. F., and Weinstock, Mildred, *idem*, vol. 62, p. 301, December, 1924. Huldshinsky, K., *Deutsche med. Wchnschr.*, vol. 45, p. 712, June 26, 1919; *Zeitschr. f. Kinderh.*, vol. 26, p. 207, September, 1920. Howland, J., and Marriott, W. M., *Quart. Journ. Med.*, vol. 11, p. 289, July, 1918. Bakwin, Harry, and Bakwin, Ruth M., *The Dosage of Ultra-Violet Radiation in Infants with Tetany*, *Journ. Amer. Med. Assoc.*, vol. 95, p. 396, Aug. 9, 1930. Casparis, H., and Kramer, B., *Bull. Johns Hopkins Hosp.*, vol. 94, p. 219, July, 1923.

⁴² Phelps, W. M., *Journ. Bone and Joint Surg.*, vol. 12, p. 253, April, 1930.

⁴³ Coblenz, W. W., and Kahler, H., *Bur. Standards Sci. Pap.* 378, 1920.

⁴⁴ Coblenz, W. W., Long, M. B., and Kahler, H., *Bur. Standards Sci. Pap.* 330, 1918.

about 10 minutes after the arc has been started. For local treatment a water-cooled quartz mercury vapor arc light is frequently employed either with or without quartz compression lens or other quartz applicators, varying with indications.

Carbon arc.—The spectral components emitted by the carbon arc are similar to sunlight, except for an additional band at 3,883 Angstrom units, but vary in intensity. The total radiation emission and the relative intensity of some of its spectral components may be altered by varying the voltage and amperage, by altering the diameter of the carbons, and by impregnating the carbons with suitable metals or salts.⁴⁵ The plain carbon arc of low amperage (from 3 to 10 amperes) has rarely proved of clinical value in local applications; those of higher amperage (20 or more amperes), especially those burning impregnated carbons, have been reported effective in general body exposures. The high intensity arc has an output of total energy closest to sunlight. Nickel, iron, titanium, aluminum, and tungsten are all employed for impregnating the carbons.⁴⁶ Groups of (from 20 to 30 amperes) carbon arc lamps are often used for irradiation of several bedridden or ambulant patients; high amperage lamps (from 50 to 125 amperes) are, as a rule, used chiefly for groups of patients. There are those utilizing 90 amperes that can irradiate 12 or more patients at a time. The cost of installation, the operation charges of large carbon arcs and the care necessary make them useful chiefly for the handling of groups of subjects in institutions.

Of the ultra-violet rays, the plain carbon arc emits chiefly the longer (near 400 millimicrons); that below 300 millimicrons is comparatively weak. Carbons with special impregnations or cores now employed in carbon arc lamps emit additional radiation characteristic of the metal or chemical employed within the carbon. Carbons impregnated with iron, tungsten, titanium, and nickel emit rich ultra-violet zones down to about 220 millimicrons; in addition, carbon-arc sources emit much infra-red and red radiation. With great energy input, carbon arcs can emit a large quantity of radiation. For best efficiency, a definite relationship must exist between the diameter of the carbons and the amperage employed.

The greater the amperage, the more heat is generated. A lower amperage arc can be operated nearer to the patient because its

⁴⁵ Coblentz, W. W., read before Illuminating Engineers Society, Chicago, Oct. 14, 1927. Luckiesh, Matthew, *Ultra-Violet Radiation*, New York, D. Van Nostrand Co., 1922. Griffith, H. D., and Taylor, J. S., *Journ. Hyg.*, vol. 25, p. 218, July, 1926; *Radiology*, vol. 10, p. 93, February, 1928.

⁴⁶ Luckiesh (footnote 45). Coblentz, W. W., *Sources of Radiation and Their Physical Characteristics*, *Journ. Amer. Med. Assoc.*, vol. 95, p. 411, Aug. 9, 1930. Coblentz, W. W., Dorcas, M. J., and Hughes, C. W., *Radiometric Measurements on the Carbon Arc and Other Sources Used in Physical Therapy*, *idem*, vol. 88, p. 390, Feb. 5, 1929.

lessened heat makes this tolerable. Hence, by the law of inverse squares, close exposures increase the quantity of light utilized. As a result, lesser amperage arcs, such as 29 amperes, with specially impregnated carbons, may prove as effective on close irradiation of single patients as high amperage arcs necessarily operated at greater distance and generally employed for groups.

Other artificial sources of light are frequently employed, especially in the European clinics. These include arcs between electrodes of tungsten, iron, magnetite, or cadmium; also oxyacetylene flames. A recent development is a combination of a mercury arc between highly incandescent electrodes of tungsten, all inclosed in a special glass (Corex) that absorbs the ultra-violet shorter than 280 millimicrons, not present in sunlight.⁴⁷ The total intensity at about 3 feet distance is about one-twelfth average solar radiation. About 1.5 per cent of the total radiation emitted consists of radiation of wave-lengths less than 313 millimicrons.

A so-called cold quartz light, also recently developed, is a glow discharge through mercury vapor, emitting mostly short ultra-violet rays shorter than those present in sunlight (90 per cent or more at 254 millimicrons). The exact place of these sources of light in therapeutics must still be fixed.

Indications for the use of various sources of light therapy are still inexact, as are also the contraindications; but in many localities in cold and cloudy seasons of the year, when sunlight is too uncertain and solar exposures are too interrupted, artificial sources of light have proved valuable aids and substitutes.

PIGMENT

Mercury-vapor arcs produce a yellowish-brown pigmentation. However, at times I have observed mercury-vapor lights produce a pigment barely distinguishable from that produced by sunlight, but it does not last as long. Pigment produced by intense sources of heat, such as oxyacetylene blasts or osram lights, is said to simulate sunlight tan closely, and to be just as permanent (Kisch). This is doubtful. The pigment from sunlight, the carbon arc and tungsten arc is blackish brown or red-brown.

That increased pigment production necessarily means an increased tendency to healing is not generally accepted. Similarly, however, the maintained production of an erythema is not a necessary accompaniment of improvement. Pigment can protect against an overdose of ultra-violet energy; it absorbs light, changing it to heat, and may allow for better heat radiation; it is doubtful whether it sensitizes

⁴⁷ Luckiesh, M., *Artificial Sunlight*, New York, D. Van Nostrand Co., 1930.

the skin to visible light as chlorophyll does the plant. Patients who failed to develop pigment have responded favorably to treatment,⁴⁸ just as patients who developed a strong pigment often failed to heal. The development of ultra-violet pigmentation is independent of that of tolerance, and ultra-violet tolerance is possible without pigmentation. A suspension of melanin has been shown to protect the frog's mesentery from ultra-violet rays.

Primary melanin deposit is in the basal cells of the malpighian layer; and the greatest absorption in this layer, according to Bachem and Reed, occurs at 300 and at 250 millimicrons. Therefore, pigment production must be due mainly to these spectral regions; and it appears to be the expression of a local response to the irritation of the prickle cells, which lie immediately above the basal cells where the pigment is deposited. In addition to the irritation, a mother substance (dioxypheylalanine or tyrosine or some closely related compound) and an enzyme (an intracellular oxidase called dopa-oxidase) are necessary.

Pigment undoubtedly is in some way correlated with increased tolerance to irradiation. It not only absorbs but radiates energy. It increases absorption to the yellow and green and so suggests an adaptation to sunlight (which has its greatest intensity in this region). It may sensitize tissues to long rays and so shift the effective threshold toward the red region; but there is no evidence of its changing short lethal rays to long nonlethal ones, as Rollier has suggested.

Of the rays that produce pigment readily, a fairly large percentage has been found to penetrate beyond the pigment-bearing cells. Pigment cells lying beneath prickle cells can not account for the increased tolerance of the latter to subsequent irradiation, unless melanin may cause systemic effects that allow for this. Chemical change produced in the corneal layer may also be a factor.⁴⁹

DOSAGE

Curative results in light therapy may be brought about without the production of marked cutaneous burn, and even the first degree of redness need not be produced. In treatment of rickets exposures with the quartz mercury arc as small as five minutes anteriorly and posteriorly twice weekly have proved curative. The skin offers a vast field of living cells, which are exposed to stimulation or injury in many ways, and such an effort may provoke immunizing or harmful effects. Certain regions of ultra-violet between 313 and 250 millimicrons produce skin erythema; about 69 per cent of the light

⁴⁸ Reyn, A., *Die Flinsenbehandlung*, Berlin, H. Meusser, 1913.

⁴⁹ See footnote 12.

erythema is caused by rays from 302 to 297 millimicrons. Four per cent of this maximum is at 313 millimicrons; 45 per cent is around 253 millimicrons. Erythema is not caused by even one hour's exposure of the skin to ultra-violet rays longer than 330 millimicrons (Hill). Rays shorter than 250 millimicrons produce a very faint erythema. Dosage in therapy with unfiltered lamps must therefore be regulated by the intensity of wave-lengths from 313 to 250 millimicrons present. Erythema varies with the intensity of the wave-lengths of those regions and the duration of exposure to the source of ultraviolet rays, the distance from the source, the temperature, and the individual sensitiveness of the skin.

The dosage of light to be used therapeutically can not be fixed, and it will vary with the disease treated. The sources of light and the individuals irradiated vary too greatly to allow of any generalization. Even different areas of the body vary greatly in their sensitiveness to radiation. Some workers prefer an erythema, others a suberythema dose; still others strongly stress the desirability of the production of pigment. The Copenhagen school, employing particularly the carbon arc light, prefers erythema.

A practical method is to aim at a faint erythema production with each dose applied. Thus skin sensitiveness is maintained. (This dose of light has produced in the hands of some workers an increased bactericidal power of the blood, whereas excessive dosage has produced a marked decrease and in animal experimentation has appeared to hasten death.) Overheating of the body is avoided by using short and intense exposures. The degree of skin erythema may guide in regulating dosage. Exfoliating skin is very opaque to ultra-violet rays, while newly exposed skin is very sensitive. The skin is rested during desquamation and several days elapse before further exposure to this area. When the skin becomes insensitive, say to large doses of mercury-vapor quartz light, an exposure to long-flame carbon arcs is employed. When pigment is established by this source, so that a long exposure is now required to produce redness, this exposure can be reduced by using nickel-cored or tungsten-cored carbons. The method requires only 15 minutes' maximum radiation in contrast to the Finsen method, with which a 2-hour exposure is the rule.⁵⁰ Skin colorimeters have been made aiming to measure varying degrees of erythema; but their accuracy is questioned. Rollier and his followers, on the other hand, aim for pigment production.

Overdosage of light may produce injury, although nature has left a wide margin of safety. Excessive exposure has caused a drop in the bactericidal power of the blood with malaise and fatigue.

⁵⁰ Eldinow, A., *Med. Journ. and Rec.*, vol. 130, p. 695, Dec. 18, 1929.

During menstruation the blood bactericidal power was lowered and irradiation appeared to make this even worse.⁵¹ In experiments in which rabbits were given a septicemia, the bactericidal power of the blood fell to a very low degree and was not improved by irradiation, thus supporting the view generally held that in the treatment of acute infections by light one should be very cautious. Very aged patients have been considered to have their resistance to infection lowered by the injudicious application of light.⁵² In tuberculosis overdosage has produced focal reactions that have done harm; light may set up a focal reaction similar to that of tuberculin. In anemic rats careful irradiation has led to a rapid regeneration of erythrocytes and hemoglobin; but if the irradiation was too vigorous, blood cells were destroyed.⁵³ Overexposure to ultra-violet has rendered ergosterol inactive against rickets. On the other hand, prolonged and intense irradiation of rats with ultra-violet (over a period of six months) had no unfavorable effect on the rate of growth or on the size or appearance of the endocrine glands.

In some cutaneous disorders (eczema, psoriasis, lupus erythematosus, herpes simplex, erythema solare perstans, xeroderma pigmentosum, freckles, atrophy, keratoses, prematurely senile skin) exposure to such rays may cause an exacerbation, provoke an attack, or produce other injurious effects.

The schedule for increasing the period of exposures with various sources of light must vary. The physician is to be guided chiefly by the signs and symptoms evinced by the patients in their response to treatment, in addition to the skin reactions. Furthermore, in disease such as tuberculosis, the selection of a form of light therapy may depend on the state of activity or on the type of disease to be treated; thus, with a febrile advanced case, one would usually prefer to avoid using heat rays. One may also have to depend on the source of light available or be influenced by the season of the year. Furthermore, a failure in response to one form of light therapy may be an indication for the trial of another form, or possibly many forms of light therapy may have to be combined in various ways. I have found that some patients with sallow complexion showed little skin erythema on the first exposure to the mercury-vapor quartz lamp, but if previously treated with from three to four doses of the carbon arc lamp they later reacted with erythema. There may exist contraindications to light therapy which are not yet clearly understood but which later with more experience may become evident.

⁵¹ See footnote 38.

⁵² Gauvain, H., Lecture to the National Tuberculosis Association, Washington, D. C., 1927.

⁵³ Kestner, O., *Zeltschr. f. Biol.*, vol. 73, p. 1, 1921.

It is highly probable that, in most forms of progressive acute tuberculosis, light therapy is not indicated. It is well known that roentgen therapy is not indicated in such cases. In my experience, intestinal tuberculosis is an exception. In this complication at times, even when progressively active, mercury-vapor quartz light has seemingly been of great value.

With any form of tuberculosis, light is used merely as an adjuvant and should be combined with every other possible aid. The mainstays of treatment still exist in rest, good food, and hygienic outdoor life.

With bone and joint tuberculosis, orthopedic treatment with immobilization and traction is absolutely essential while light exposure is being employed. Surgical intervention is occasionally needed, especially for the aspiration of abscesses or for hastening the expulsion of sequestrums. Joint resection and surgical fusion are necessary less often with heliotherapy, but there may even yet be certain social, economic, and other factors, as well as the stage of the disease, that occasionally force this intervention. The plaster cast is less often needed. As pointed out earlier, one always combines general and local light exposures, regardless of the location of the lesion.

TECHNIC OF EXPOSURES

With sunlight, the patients are graduated to increasing periods of exposures over increasingly large areas of the body according to Rollier's technic. Sunlight of the lowlands and highlands can both be employed clinically, but the heat of the day should be avoided.⁵⁴ Diffuse daylight and air exposures on cloudy days are used to great advantage. Chilling winds should be avoided. Overexposures may incite latent foci of disease to activity. It is important that patients during and after solar exposures feel as well as or better than they do before taking them. Headaches, restlessness, nervousness, or irritability, elevation of body temperature or pulse rate are all indications of undue reactions that call for some change in the program of solar exposures.

With plain carbon arcs, as used at the Finsen Institute, one begins with a 15-minute irradiation, front and back, and then increases daily 15 minutes front and back until exposures of 2 hours daily are reached. The lamps are placed at a distance from the patient, so that the heat emitted from this source of light is tolerable. Frequently, sweating occurs during the exposures. The treatment is then terminated with a sponge bath. General body exposures are

⁵⁴ Rollier, Auguste, *Heliotherapy*, New York, Oxford University Press, 1923; *Strahlentherapie*, vol. 28, p. 259, 1928.

always employed, and, if possible, an additional local exposure is made. In these cases as much skin surface as possible is irradiated. With impregnated carbons, depending on the cores and the amperage employed, one can gage the dosage by watching for skin erythema and the general constitutional reactions. With these one must feel one's way cautiously by first using very small exposures. With a 90-ampere carbon arc, beginning exposures of one-half minute are made, at a distance fixed for various makes of apparatus—usually above 6 feet—and perhaps 20 minutes secures the maximum exposure. Although with the Finsen arcs of thick carbons, exposures of 2 hours are made, 15 minutes is the longest time with the long-flame arcs. The aim has been to determine the optimal amount of skin to be exposed. Thus, a method of exposure of only limited skin areas such as the thorax or back, with a new area every other day so as to utilize four parts and return to the area of the first exposure on the tenth day, has given very favorable results. The skin is thus maintained in a light-sensitive state, and no exposure is given during desquamation. The question of the advisability of such a manner of irradiation is not yet solved.

With a new mercury-vapor quartz light, alternating current of 5 amperes, 110 volts, I have also made exposures purely on an empiric basis, beginning with one minute at a distance of 36 inches from the body, employing two exposures in front and two behind, and centering over the middle of the upper and lower halves of the body in order to expose uniformly as much of the skin surface as possible; a fifth exposure is then made directly over the area of disease to include any possible reflex depth action; a daily increase of one minute is added to the exposure until a 10 or rarely 20 minute period is reached front and back at this distance on all five parts. The room temperature is maintained at about 70° F. Ventilation is employed, so that the patient senses the movement of air. Heat lights (carbon incandescent bulbs) are added, if the patient is not able to endure the ventilation without discomfort. With older burners, dosage is increased more rapidly.

The quartz burner is then slowly brought nearer to the body by lowering it about 1 inch every other day until it is 18 inches from the skin if no redness of the skin occurs with the previous dose. After this, the second intensity is frequently employed, especially if the burner is one that has had considerable usage. In addition to the general body exposures with the air-cooled mercury-vapor light, a contact exposure is often made to a superficial focus of disease by means of an applicator attached to the water-cooled mercury-vapor light.

More recently I have been decreasing the dose, exposing only every other day, and on less skin area, aiming rather for suberythema dosage. The results are apparently as favorable as with the procedure already outlined.

CLINICAL RESULTS

It has been scientifically proved that a certain region of ultra-violet radiation produces a vitamin D-like substance, and it therefore favorably affects calcium metabolism in calcium-deficient disease.⁵⁵ Thus, clinically, ultra-violet is most effective in rickets, tetany, and osteomalacia. Its value in overcoming a demineralization of the pregnant and nursing mother presents favorable substantial evidence.⁵⁶ The empiric results are strongly impressive when light is used as an aid in certain skin diseases, superficial ulcerations, and many forms of extrapulmonary tuberculosis. Serious workers will deplore the extravagant claims which have from time to time been made for the therapeutic effectiveness of ultra-violet radiation covering so many diseases that it is impossible to enumerate the entire list. It must be left to the future to substantiate and disprove reported favorable clinical results in conditions such as secondary and pernicious anemias, nasal sinusitis, hay fever, common colds, catarrh, asthma, or carbon monoxide poisoning, and many skin diseases. Light has repeatedly been quoted as an important tonic agent and one that will raise resistance against most systemic infections, without proof of action. Colored glasses placed over lamps have also frequently been so advocated.

In skin diseases ultra-violet has proved truly of great value when used locally and generally in the treatment of lupus vulgaris and scrofuloderma. It has occasionally been found useful in acne vulgaris, psoriasis, indolent ulcers, pityriasis rosea (in erythema doses), adenoma sebaceum (in blistering doses), and erythema induratum. It has been of questionable value in the treatment of boils and generalized staphylococcus infections of the skin, and alopecia. It has generally not fulfilled the promise of earlier reports in the treatment of lupus erythematosus.

In tuberculosis light of any form by itself is not curative but comprises only one of the important adjuvants in treatment. To believe that sunlight or lamps will cure all forms of extrapulmonary tuberculosis, to be unduly optimistic about this treatment and consider it specific, to use it without sound medical guidance and adequate equip-

⁵⁵ Maughan, Sonne, Reerink and Wijk, and Hess and Weinstock (footnote 41). Steenbock and Black (footnote 27).

⁵⁶ Huldshinsky, Howland and Marriott, Bakwin, H., and Bakwin, Ruth M., and Casparis and Kramer (footnote 41).

ment, and to use it to the exclusion of rest and the hygienic-dietetic regimen in the open, eliminating orthopedic measures or the occasional necessary surgical intervention, will bring discredit to a really desirable form of treatment.

If one employs light as an aid only, the most favorable response to solar exposures has been shown in the so-called pretuberculosis of children and tuberculosis of the lymph nodes (including hilus), pleura, bones and joints, peritoneum, and intestine.

Less favorable results (yet often good) are obtained in genito-urinary, laryngeal, ocular, aural, and cutaneous tuberculosis. Pulmonary tuberculosis I do not consider an indication for light therapy. With joint tuberculosis, Rollier claims the fibrous form of ankylosis has been overcome and the joint function has been restored, but how permanent these favorable results will prove to be can not be stated. Restoration of function may occur in the synovial form of joint tuberculosis even after large effusions have been absorbed; but one is still entitled to doubt a functional return of motion in a joint when the bony parts have been destroyed to any degree. Orthopedic measures still play the major rôle in bone and joint tuberculosis; and intervention by surgical fusion should always be considered in cases of advanced bony destruction. With lymph node disease, massive tuberculosis glands have been extruded from their capsules during healing by light. Fistulas are most resistant to treatment.

With plain or cored carbon arcs of high amperage (from 55 to 75 amperes) or with arcs of lower amperage (from 20 to 29 amperes), the best results have been reported with cutaneous and ocular (corneal and phlyctenular) tuberculosis and that of the bones and joints, lymph nodes, larynx, peritoneum, and intestines; less favorable have been the reports on pulmonary and genito-urinary tuberculosis.

In my own experience with the use of the quartz mercury-vapor light as an adjuvant, the most favorable response has been encountered in intestinal tuberculosis. The diagnosis is established by a history of all varied digestive complaints, such as alternating constipation and diarrhea, nausea, vomiting, abdominal pain, soft or watery stools, or merely by persistent loss of weight or slight elevation of temperature otherwise unexplained—by any or all of these symptoms combined with roentgen demonstration of spasm or filling defect in the cecum or ascending colon in a patient known to have pulmonary tuberculosis. Plate 1 shows roentgenographically the intestine with a filling defect before treatment, and an almost complete disappearance of this defect after eight months of quartz mercury-vapor exposures; this improvement was accompanied by a cessation of the digestive complaints. After the study of a large series of such

cases, of which the foregoing is typical, I am convinced that this recovery is directly related to the light therapy and occurs frequently if the disease is not of the acute progressive type and if the patient's condition is not too poor. However, these are only clinical impressions, and experimental proof is yet needed.

Other forms of tuberculosis which in my experience are frequently helped by mercury are light exposures (when light is used only as an aid) are the "hilus glandular," or so-called hidden tuberculosis of children and adults, and the superficial forms of tuberculosis, such as the cutaneous, oral or pharyngeal, laryngeal (except the acute and the edematous forms), corneal and phlyctenular ocular tuberculosis, and the lymph node and peritoneal tuberculosis. Less favorable in their response but yet often improved are genito-urinary, and bone and joint tuberculosis. Postoperative sinuses after nephrectomy are especially responsive.

Reliance on any source of light as an important aid in pulmonary tuberculosis is not to be encouraged.

From the foregoing presentation of the present status of light therapy it is evident that harm may be done by the injudicious and uninformed use of light. Valuable as this method has proved itself to be in a limited number of diseases, it is surely clear that much more investigation and many more scientific data are required before light should be generally prescribed by those unfamiliar with the contraindications and the details of its application.



1. FILLING DEFECT IN CECUM BEFORE TREATMENT



2. ABSENCE OF FILLING DEFECT AFTER TREATMENT

THE RISE OF MAN AND MODERN RESEARCH¹

By JAMES H. BREASTED

[With 7 plates]

There are few if any men of science to-day who would reject the conclusion that physical man is a product of evolution from lower forms of life. As we look at the subsequent career of early man we find that we know very little about his rise until he enters the Historic Age, commonly regarded as beginning with European history. Between the emergence of physical man on the one hand and on the other the beginning of the historical period commonly identified with European history, there lies an enormous period of at least a million years, which is to a large extent a gap in our knowledge. Consider that gap for a moment. On the other side of it the bestial savage, Caliban on Setebos, the merely physical man—on the nearer side civilized Europe! In the tremendous chasm that lies between, falls the entire development of the mind of man, from his emergence as the first implement-making creature, and thence upward through the conquest of civilization to the dawn of European history. In brief, the whole story of man's emergence from the deeps of merely physical existence, the story of the Rise of Man, must be found in the great gap. There lies the triumphant development of the human mind beginning with physical man as a mere mammal struggling for survival among all the other mammals and eventually gaining complete supremacy over them all as he achieved the conquest of civilization. We thus have before us three great periods or processes: First, the rise of life on the earth, culminating in the evolution of physical man; second, the great period which I am calling the Rise of Man, still so vague and obscure in the darkness of our ignorance; and third, European history, or the history of western man. Since the days of Locke the philosophers have more or less fully recognized the fact not only that man arose out of nature but also that man and nature are one. The conclusion was essentially philosophical. Our second period, the Rise of Man, is now yielding the evidence which demonstrates historically that man, with all his mental endowment, has arisen out of nature.

¹ Address delivered at the annual meeting of the National Academy of Sciences, Washington, D. C., Apr. 27, 1931, and since then edited and brought down to date.

LACK OF ORGANIZED INVESTIGATION OF THE RISE OF MAN

The study of the first of these three periods is the task of natural science, especially of the geologists and the paleontologists. This prehuman period is being vigorously investigated in all the great centers of science of the world, such as the American Museum of Natural History in New York, under the able leadership of Henry Fairfield Osborn. It is needless to state that the third of these periods—the Age of Historic Man, so commonly identified in general terms with European history—is being studied in exhaustive researches by highly trained specialists, the historians of Europe and America. It is a remarkable fact that the Rise of Man, the middle period of the three which I have mentioned, is nowhere represented by a systematically organized corps of investigators operating on a large and general plan with all its subordinate parts carefully correlated. This Rise of Man, which brought about human supremacy on our globe, this conquest of civilization, a period covering at least several hundred thousand years, constitutes, as I have elsewhere affirmed, the greatest event in the history of the universe in so far as it is known to us. But strange to say, there has existed heretofore no body of scientific investigators organized especially for the study of that tremendous transformation which I am calling the Rise of Man.

THE ORIENTAL INSTITUTE ORGANIZED TO STUDY THE RISE OF MAN

Thirteen years ago, before the National Academy was housed in its present beautiful home—that is, in April, 1919—I had the honor of delivering the last course of the William Ellery Hale lectures before this distinguished body. These courses of lectures, as you will recall, had been planned by our illustrious colleague, Dr. George E. Hale, for the purpose of tracing evolutionary development beginning with the constitution of matter, which was presented in the first course of lectures by Sir Ernest Rutherford. He was followed by a group of distinguished natural scientists who traced the development through ever higher forms up to the appearance of man. Feeling very insignificant by contrast with these eminent natural scientists who preceded him, the embarrassed humanist who is now addressing you endeavored to sketch the culminating events of this age-long development in the final course of Hale lectures on the Origins of Civilization. In preparing the materials for that course of lectures I was, as I had been for years, painfully aware of the lack of any large and comprehensively organized agency for investigating the Rise of Man. Working individually and alone, with but slight institutional support, we orientalists have long stood with the geologists and paleontologists at one elbow and the historians at

the other. We thus have on one side highly organized groups of natural scientists and on the other a large body of trained historians; but we ourselves have had no organization for the study of the Rise of Man. In May, 1919, a few weeks after delivering the William Ellery Hale lectures, I received from Mr. John D. Rockefeller, jr., a very cordial letter agreeing to finance the nucleus of a staff to begin organized investigation of the Rise of Man. Out of this beginning of 13 years ago this new organization, which we call The Oriental Institute, has rapidly grown from the conduct of a single expedition on the Nile to an organization which is not only maintaining a group of trained investigators at the American headquarters at the University of Chicago but also serves as the administrative and scientific center operating a series of research expeditions at 12 different points in the ancient Near East, with a personnel of over a hundred people.

Genetically the work of the Oriental Institute, as I have already indicated, falls between that of the paleontologists, on the one hand, and of the historians, on the other. Geographically it includes the vague region commonly called the Near East. If we lay out upon a map of the eastern Mediterranean region a circle having a diameter of something over 2,000 miles, we find that it includes the great centers where man began as a savage and eventually created the civilization which we have inherited. The region stretches from the Black Sea on the north to the cataracts of the Nile on the south, and from the Aegean and the Greek Islands on the west to the Persian Plateau on the east. For an individual scientist to undertake, single handed, the recovery and the study of the vast body of evidence still surviving in this extensive region would be pathetically futile. The task must be attacked by a large organization subdivided into groups or expeditions. The Oriental Institute therefore has now a group of 12 research projects strategically distributed throughout the ancient lands of the Near East and stretching along a curving frontier of over 2,500 miles, from the Black Sea on the north to the cataracts of the Nile on the south.

THE PREHISTORIC SURVEY

It is obvious that the study of earliest man must carry the investigator back into the geological ages, and our researches in the Near East, therefore, have been to no small extent concerned with the problems of natural science, especially geology. We have, therefore, organized a Prehistoric Survey, under the leadership of Dr. Kenneth S. Sandford, an experienced geologist, as field director. This expedition undertook first the investigation of the geological history of the Nile Valley. The results have been notable. There are still

many gaps in our geological knowledge of this area of northeastern Africa, but our prehistoric survey has been able to follow the successive stages of the geological history of the Nile, notwithstanding the unavoidable gaps. Back in Oligocene time, millions of years ago, the river began as a colossal but meandering stream carrying northward the drainage of all Northeast Africa across the North African Plateau to the predecessor of the Mediterranean Sea. It transported enormous masses of gravel, which now overlies vast areas of the North African Plateau. Here and there lie scattered also silicified or



FIGURE 1.—Map showing the field operations of the Oriental Institute in the Near East

petrified tree trunks as much as 70 feet long, brought down on the waters of this mighty Oligocene river. There is no evidence of man's presence along this earliest Nile.

EARLIEST EVIDENCES OF MAN YET DISCOVERED IN THE NEAR EAST

Somewhat east of its earliest course this drainage began to cut a channel which finally deepened and expanded into the present Nile Valley. As its volume diminished the shrinking river left on either hand a series of terraces, in which our Prehistoric Survey has discovered early implements of Stone Age man buried in the structure of the terraces as in the river terraces of Europe. Along a section of the ancient river bed now dry, and belonging to the early stages of the Nile in its present valley, the survey discovered a stretch of over 60 miles of the early Nile bed some 60 feet in depth, and at the bot-

tom of this gravel bed they found stone implements wrought by the hands of man and marking for us the advent of man in Egypt. The age of these implements must be Plio-Pleistocene—that is, in terms of European geological history at the beginning of the European Ice Age, although there was of course no Ice Age in North Africa. These implements are therefore the oldest human artifacts ever yet found in the Near East, and may date anywhere from several hundred thousand to a million years ago.

DISCOVERY OF THE DATE OF THE DESICCATION OF NORTH AFRICA AND THE AGE OF THE SAHARA

Even more important than this new observation is a group of very instructive discoveries made by the Prehistoric Survey in the Faiyum Lake depression in the Sahara Plateau on the west side of the Nile, 60 miles above Cairo. Here a series of lake terraces, discovered by the survey, were linked up in age with those in the Nile Valley. As many as 10 of these lake terraces were found lying in a series one below another. As the high level of the prehistoric lake, 112 feet above the sea, gradually sank age by age to its present level below the sea, the waters stopped long enough at successive levels to leave these terraces. The lake was shrinking as a result of the desiccation of North Africa, and these terraces, like the sinking sand



FIGURE 2.—Sketch map of Egypt, showing the area thus far included in the Prehistoric Survey

in an hourglass, mark off both the falling waters of the lake and the advancing desiccation of North Africa. This piece of research has thus, for the first time, disclosed the date of the desiccation which created the Sahara Desert. This date is not in terms of years, but in terms of human culture. It was in the middle of this Old Stone Age commonly called Paleolithic, when the lake was still at a level far above the sea, that the desiccation of North Africa began. Such a tremendous change completely transformed the life of man on the North African Plateau, and the discovery that Paleolithic man was exposed to this change is one of epoch-making importance. Thus we learn that while Paleolithic man was exposed to the advance of the ice and the rigors of the Ice Age on the north side of the Mediterranean, on the south side he was exposed to the desiccation that transformed his fertile plateau home into the present Sahara Desert. What was to be the result?

DESICCATION OF NORTH AFRICA AND THE RISE OF MAN

Before the desiccation set in, the entire North African Plateau was without doubt plentifully watered and was inhabited by the earliest hunters whom we know on the African Continent. The evidences of their presence are distributed far across the Sahara from the Nile to Morocco, in remote and inaccessible desert regions which no hunter, however daring, would now venture to visit with any hope of returning alive across the waterless waste. With the advance of the desiccation these hunters were forced to take refuge in the Nile Valley, where there was plentiful water. The animals which they had been commonly pursuing on the plateau probably preceded them in great numbers to the bottom of the valley. This close association of the hunter with the animals he pursued, due directly to the desiccation which drove them both into the Nile Valley, was without any doubt one of the influences which brought about the domestication of animals. In a situation otherwise completely desert, the plentiful water obtainable along the shores of the Nile likewise contributed to the development of earliest agriculture, especially after the Egyptians invented the plow. The surviving evidences left by these processes are buried deep under the Nile alluvium, which has been deposited by the river during the last 15,000 or 20,000 years and perhaps longer. In boring an artesian well at the new Luxor headquarters of the Oriental Institute the drill brought up pottery at a depth of 75 feet.

On the basis of these two possessions, cattle-breeding and agriculture, there arose in the Nile Valley the earliest known social and governmental structure—the earliest organized nation of several million souls—a government, the emergence of which was itself the

dawn of civilization. Thus began an extraordinary social evolution much of which we can follow. Although its earliest stages elude us, we have in the prehistoric cemeteries along the Nile a vast body of fact and information concerning the earliest conquests which lifted man from savagery to civilization, and form the oldest evidences of the advance of man's developing mind.

SALVAGING THE EARLIEST BUILDINGS AND INSCRIPTIONS PRODUCED BY CIVILIZED MAN

As organized government advanced the monumental age began, and the volume of evidence greatly increased. The vast cemeteries of massive stone tombs with which Nile travelers are familiar along the margin of the desert from Gizeh southward for 60 or 70 miles are an illustration of the enormous body of unsalvaged evidence which still remains to be recorded and saved for science in the ancient Near East. It is the salvaging of this evidence which constitutes probably the most important of the numerous responsibilities of modern science in this region at the present day. The Oriental Institute has therefore organized a group of staffs trained, equipped, and adequately supported, to salvage this perishing evidence at every possible point. At Sakkara, the cemetery of ancient Memphis, the reliefs in the tomb chapels of 5,000 years ago, often with beautifully preserved original colors, depict the whole range of ancient human life, especially cattle breeding, agriculture, and highly diversified industries. The expedition which is just beginning the work of copying these scenes in facsimile and publishing them in color is under the field directorship of Prof. Prentice Duell, formerly of Bryn Mawr College. These remarkable materials when published will fill five folio volumes 24 inches high.

THE DAWN OF CONSCIENCE

With the development of the social fabric which arose on the material basis so clearly disclosed in these early tombs, moral sensibility appeared as early as the middle of the fourth millennium B. C., and the sense of social responsibility also later arose for the first time. Man began to contemplate society and to reflect upon the quality of human conduct. Thus emerged a new realm of social and moral values, which man began to observe for the first time. Conscience gained influence and began to be a social force. This fundamental step in human advance is disclosed to us in the centuries before 2000 B. C. in a large body of writings which we call the "Coffin Texts," because they are written on the insides of ancient Egyptian coffins. For the last eight years, under the editorship of Dr. Alan H. Gardiner, of London, and Dr. Adriaan de Buck, of the

University of Leyden, the institute has been exhaustively copying the thousands of lines of "Coffin Texts" preserved in the ancient coffins at Cairo and in the various museums of Europe and America. When these important texts have been carefully edited and published by these two scholars of the institute staff, it will be possible to date the dawn of the Age of Conscience just as we date the beginnings of the Age of Metal.

EARLIEST EVIDENCE OF A SCIENTIFIC ATTITUDE OF MIND

At the same time the institute has been greatly interested in the development of the human mind as disclosed in the beginnings of science. It has therefore recently published the earliest known surgical treatise, an extraordinary papyrus now in the collections of the New York Historical Society. This treatise, written toward 3000 B. C., that is, nearly 5,000 years ago, discloses for the first time the beginnings of a scientific attitude of mind and is therefore the earliest known document in the history of science. It is commonly known as the "Edwin Smith Surgical Papyrus," after the name of the owner, the earliest American Egyptologist, who lived in Luxor and purchased the papyrus there in 1863.

THE GREAT MONUMENTS OF THE IMPERIAL AGE

After 2000 B. C. the national developments all around the eastern end of the Mediterranean led to international rivalries and the Imperial Age began. Early in the sixteenth century B. C. Egypt gained a leading position and for 400 years was imperial mistress of the ancient Oriental world. As the first world power Egypt was able to erect colossal monuments, many of which now survive and await rescue and study. This vast group of monuments forms the largest body of evidence which still lies unsalvaged in the ancient Near East. It consists chiefly of the inscriptions and reliefs on the walls of the great tombs and temples of the Nile. In association with the Egypt Exploration Society, the institute is saving the records of the beautiful Temple of Seti I at Abydos and publishing them in color in a series of folios, of which the first volume is slowly nearing completion. This field work is being carried on by an able woman, Miss Amice M. Calverley. At Ancient Thebes, known to the general public more widely as Luxor, the institute has been working for six years at the colossal Temple of Medinet Habu and others connected with it. It has recently issued the first volume of a series of 10 or 12 folios, which for all time will save for historical science the enormous body of inscribed and sculptured records covering the walls of the Medinet Habu temples. These records, dating from 1200 B. C., are of particular importance, because they disclose

Europe for the first time entering the arena of oriental history, and reveal to us the migrations which carried the Etruscans from Asia Minor to Italy. The expedition doing the work on these records is the largest which the institute has in the field and is conducted by Dr. Harold H. Nelson as field director.

EGYPTIAN PALACE ARCHITECTURE RECOVERED FOR THE FIRST TIME

At this place the same expedition is conducting extensive excavations in order to recover the architecture of the buildings. This project has been under the immediate leadership of Prof. Uvo Hoelscher. For the first time we have now before us in surprising completeness the architecture of a Pharaoh's royal palace. To our surprise, Hoelscher's excavations and penetrating observations have disclosed quite clearly that the largest halls of a Pharaoh's palace had vaulted ceilings, and were not therefore flat-roofed like the Egyptian temples, as we had formerly supposed. This unexpected discovery is of great importance in the history of architecture. These palace halls, with high vault over the central axis and lower vault on either side, are undoubtedly part of the ancestry of the clerestory architecture of Europe, with high nave and lower side aisles.

NEW ORIENTAL INSTITUTE HEADQUARTERS AT LUXOR

This work of salvaging the evidence from the temples and tombs of the Nile has developed so rapidly in the plans of the institute that it was decided to establish permanent headquarters with appropriate buildings on the east side of the Nile at Luxor. The institute therefore purchased a tract of $3\frac{1}{2}$ acres facing the Nile on the northern fringes of the modern town of Luxor and almost under the shadow of the great Karnak temple. This expedition of the institute with its personnel of over a score, who have been living beside the great Medinet Habu temples on the west side of the Nile, has now moved into the buildings of the new headquarters on the east side. Here is a large residential house, with spacious social rooms; the whole connected by an arcade with a neighboring building, containing library, offices, a large drafting room, and plentiful workrooms. Besides these two, there is another building containing photographic laboratories, a garage for the cars of the expedition, an outlying building for laundry, besides work shops and servants' quarters. These buildings are of burned brick, steel, and concrete. Designed in the southern California-Spanish mission style, they stretch along the river with a frontage of over 350 feet, and will form the outstanding scientific center for the operations of the institute in the Near East, as well as the Egyptian headquarters.

The institute is also active in the great Theban cemetery, where Mrs. Nina de G. Davies has long been engaged in copying in color facsimiles the ancient paintings on the walls of the tombs. Under the editorship of Dr. Alan H. Gardiner, who supported this work for years, these paintings of Mrs. Davies, together with an additional series which she is now engaged in making, will be published by the institute in color, in a series of 115 color plates, occupying two folio volumes.

It will thus be seen that as far as the early human career in North-eastern Africa is concerned, the institute is salvaging and studying the evidence along a chronological series of periods extending from the geological ages down to the emergence of Europe in the history of the east.

NINE ANCIENT CITIES BEING EXCAVATED IN WESTERN ASIA

In Asia a similar program has been undertaken, modified, however, by the fact that the climatic conditions and the character of the monuments have contributed to the perservation of a different type of materials. Certain kinds of written evidence are better preserved in Asia than in rainless Egypt. This is especially true of cuneiform tablets when they have been fired in an oven so that they become pottery. Far across the hills and valleys of western Asia, from Anatolia to Persia, stretches a vast array of city mounds covering great archives of cuneiform tablets, and the process of salvaging these materials has still been hardly more than begun. Behind this historic age of writing there lies a period of many thousands of years of prehistoric development which must be investigated by a prehistoric survey like that which we have had in Egypt. Meantime the study of the human career in western Asia is not yet in a position to disclose any such remote sequence of development as the Oriental Institute has found in Northeastern Africa.

Thus far the researches of the institute in western Asia have been concerned chiefly with the Age of Writing, and especially with the early developments in the Tigris-Euphrates region. Some 30 to 40 miles north-northeast of Baghdad the institute has a concession to excavate a group of four ancient cities lying in a circle only some 15 miles in diameter. At Tell Asmar, the most important of the four, the institute has put up a considerable field house which is now the headquarters of its operations in ancient Iraq. This project is under the charge of Dr. Henri Frankfort, as field director. In immediate charge of the work at the second neighboring site, called Khafaji, Doctor Frankfort had for one season Dr. Conrad Preusser associated with him. By the introduction of modern transportation it is possible to carry on the investigation of these two

sites, and eventually also the two others forming the group of four, from the single center at the Tell Asmar house.

The importance of these researches lies in the fact that this region on the east of the Tigris stretches eastward toward the Persian Mountains and the eastern end of the Highland Zone, as we call it, the high and mountainous belt of country that extends from the Persian Plateau westward through Anatolia to the Balkans in Europe. This Highland Zone was inhabited by a group of round-headed people like the Hittites and the Armenians, who developed a civilization, the variations of which are closely related to each other and which may be called the Highland Civilization. These Highland peoples overflowed constantly to the lowlands on the south. At Tell Asmar and Khafaji we have evidences of this overflow, which even extended as far west as the region of Baghdad.

The work at this site has been aided by airplane observation, at first kindly made for the institute by the British Air Force and later from an Imperial Airways plane chartered by the institute. The grass, which, supported by the winter rains, grows chiefly in the spring, does not grow on a surface covering the walls in such an ancient site. The absence of the grass therefore discloses the ancient walls lying beneath the surface of the present desert. Indeed, when an air photograph of desert surface has been developed in the dark room the lines of ancient walls may be traced quite clearly as betrayed by the absence of the grass. Although the old walls themselves, because they are buried beneath the surface, are invisible, their ground plan is thus revealed to the investigator by the air photograph. At Tell Asmar and Khafaji the topmost strata belong to an age before 2000 B. C., in general the age of the great lawgiver Hammurapi, and it is clear, therefore, that the lower levels must be of much greater age. The lower levels will reveal to us earlier stages of Sumerian history and will disclose especially their relations with the Highland peoples on the north. A large palace of Sumerian age has been discovered at Tell Asmar and will be entirely laid bare next season. At Khafaji we have uncovered a fortified inclosure with temples and dwellings.

AN UNKNOWN CITY OF THE HITTITES

The most important of these Highland peoples were the Hittites, whose chief states and leading cities were in Anatolia. Here the Oriental Institute has been actively engaged in exploration and excavation for the past five years. These Hittite researches have been under the field directorship of Dr. H. H. von der Osten, and for a time also Dr. Erich Schmidt. Doctor von der Osten's explorations have been fruitful in the discovery of new sites, and the statement that he

has been able to place on the map several score of ancient settlements and town sites which were unknown before may illustrate the fact that almost nothing has been done in this region. In excavation the institute has been occupied with the great mound of Alishar, southeast of Ankara. The recent decipherment of Hittite cuneiform has made it possible to read their clay-tablet records which had heretofore been found at only two places in Asia Minor—the ancient Hittite capital of Hattusas and a commercial settlement now known as the Kül Tepe. The institute's discovery of cuneiform tablets at Alishar therefore added a third Hittite city to those already known to have left records in cuneiform writing. One of these tablets from Alishar contains the name of the earliest known Hittite king, enabling us to date it from a very early stage of Hittite history, reaching back a century or two earlier than 2000 B. C. The excavation at Alishar is the first such investigation which has carefully plotted all the ancient levels stratigraphically. These excavations have therefore disclosed for the first time the successive stages of ancient life in Anatolia, from the Stone Age at the bottom, over 85 feet below, to the latest Seljuk Turkish levels at the top, a range of some 5,000 years. Thus for the first time this expedition has identified and listed the types of Anatolian pottery, which are the archeologist's fossils for dating the levels in an ancient city mound, as the fossils found in the rocks date the strata for the geologist. These types of pottery, thus stratigraphically recorded and dated, now furnish the history of pottery so fundamental to further archeological investigation, available for the first time in Hittite territory, in the published reports of the institute on this excavation.

EXCAVATION OF THE PALACES OF DARIUS AND XERXES AT PERSEPOLIS

The Hittites must have occupied the region of Anatolia at the west end of the Highland Zone, well back toward 3000 B. C., if not earlier. The outstanding people on the east end of the Highland Zone, however, familiar to us as the Persians, were very late intruders. The Highland Civilization of this region in pre-Persian days was of great importance in its influence on early Babylonia, and, as already mentioned, the institute is investigating several sites in the neighboring lowlands which the Highland invaders founded or captured as they shifted thither. In the study of the rise of civilization it is necessary to investigate the earliest culture discernible at the eastern end of the Highland Zone in very remote pre-Persian days. As a first step toward such investigations the institute is just beginning the excavation of the magnificent Persian capital of Persepolis. This Persian expedition is under Prof. Ernst Herzfeld, of Berlin,

as field director. In connection with the investigation and restoration of these magnificent palaces of the Persian Emperors, especially of Darius and Xerxes, the institute has begun a series of researches in the vicinity of Persepolis which will carry our knowledge back of Persian days into the pre-Persian Highland Civilization, which has left numerous city mounds still untouched by excavation and scattered far and wide across the Persian hills and valleys. The Persepolis expedition when the institute received the concession was the first scientific project of America within the limits of modern Persia.

THE EXCAVATION OF ARMAGEDDON IN PALESTINE

South of the Highland Zone is the great desert bay which has as its cultivable fringes what we may call the "Fertile Crescent." This great crescent has Palestine at the west end, Babylonia at the east end, and Assyria in the middle. (See map, p. 414.) We have already mentioned the excavations of the institute at Tell Asmar and Khafaji, on the east end of the Fertile Crescent. It is also excavating in Palestine, at the west end. Closely involved with the shifting history of the east in the Imperial Age is the famous battlefield of Armageddon, or Megiddo, in Palestine. This plain, lying inland from Haifa, received its name from the strong fortress city of Megiddo, which dominated the plain and commanded the pass over the Carmel Range which flanks the plain on the south. It was this very pass through which Allenby advanced to his great victory on the Plain of Armageddon at the close of the World War. The institute has recently acquired control of the entire site of the historic city, an area of something over 13 acres, and is now engaged in the systematic clearance by stripping off stratum after stratum of the levels which mark the successive cities built one above the other on this ancient site. Thus far the excavation has descended to the Age of the Hebrew Kings. The stables in which Solomon kept his blooded horses, imported from Egypt for sale to the Hittites, have been uncovered; and a monument of the Pharaoh Shishak, who captured Jerusalem under Solomon's son, has also been discovered.

One of the interesting developments at this site, where the excavations are in charge of P. L. O. Guy as field director, has been the use of a small captive balloon for securing air photographs which are so valuable to the archeologist. Mr. Guy has employed a type of balloon which, though not large enough to carry an operator, nevertheless will carry a camera, the shutter of which can be operated by electricity from the ground. A small hangar has been provided for the protection of this balloon, which now makes possible a series of very useful air photographs, showing the varying plan

of the city as the excavation proceeds and descends from one chronological level to another. These air surveys now form a regular part of the record of the excavations.

EXCAVATION OF THE PALACE OF SARGON II AT KHORSABAD

The entire region south of the Highland Zone, with the exception of arid desert areas, contains city mounds of the greatest importance for completing the larger picture of the developing civilizations which intermingled in western Asia. Originally occupying the middle of the Fertile Crescent, the Assyrian civilization was a composite drawn from the lowland south and the Highland Zone on the north. The cities and palaces of the Assyrian emperors on the upper Tigris are therefore important centers from which we may draw bodies of evidence of priceless value for the study of the Rise of Man. This is especially true of the palace of Sargon II at Khorsabad, about 15 miles north of modern Mosul and ancient Nineveh, which face each other on opposite sides of the Tigris. The excavations of the institute at Khorsabad, following those of the French at the same site, have resulted in the recovery of much additional information on the architecture, besides a large series of sculptures, important both for the history of art and of civilization. The most notable piece among these sculptures is that of a vast winged bull which once adorned an entrance of the palace. These figures were called by the Assyrians and Hebrews "Cherubs," a term which was curiously misunderstood by older Biblical interpreters, and early Christian art. The colossal figure of the bull, equipped with wings and human head, is some 16 feet high and weighs 40 tons. The transportation of these pieces from the upper Tigris to the Persian Gulf and thence to New York was a problem of great difficulty. Even after reaching New York transportation problems were not eliminated, for the figure projected so far on each side of a modern steel gondola freight car that it would have been impossible for the car to pass through a tunnel. The railways had to select a route for the bull from New York to Chicago, therefore, which avoided all tunnels. He has now finally reached Chicago in safety and is duly installed in the new Oriental Institute building at the University of Chicago, which was opened to the public on December 5, 1931. This colossal piece of oriental sculpture is a mystically impressive expression of the spirit of the ancient east, and graphically suggests the vast body of evidence from its ancient cities, now converging from so many different points of the compass on the headquarters of the Oriental Institute at Chicago.

The organization whose far-reaching results converge on this central headquarters has been made possible by the General Education Board, the International Education Board, and above all by the

support of John D. Rockefeller, jr. His personal interest, which has included a journey to the Near East for personal inspection of the field work of the institute, has created a new era in the study of human origins. The new home of the Oriental Institute in Chicago is a gift of the International Education Board, which he created. In this unique laboratory for the study of the unfolding life of man there is now gradually accumulating a body of selected and co-ordinated evidence such as has not been available before.

We have endeavored to suggest the great drift of human development from east to west (pl. 7, fig. 2) in a sculpture occupying the tympanum over the entrance door of the new building of the Oriental Institute at Chicago. The civilized developments suggested in this sculpture on the left, filling up and bridging over the great chasm between the emergence of physical man and western civilization, restore to us the unbroken continuity of the unfolding life of man on earth, till we are able to see it in uninterrupted sequence from the trilobite to Benjamin Franklin and Abraham Lincoln. Against the vast deeps of this vista even the catastrophe of a world war sinks into insignificance, and the voices of our Spenglers, our Keyserlings, and all the other superficial pessimists vanish without an echo. We see that to-day man is still standing in the dawn of civilization—in the first glow of that dawn. The light which diffuses that glow has been brightening for several hundred thousand years. There is no indication that it will cease to grow. It is the story of that growing light which is revealed to us in the Rise of Man.

EXPLANATION OF PLATES

PLATE 1

FIGURE 1. The new Oriental Institute building at the University of Chicago seen from the northwest. The results of the institute's field operations, which extend from Turkey on the north, through Syria, Palestine, Iraq, and Persia, to upper Egypt on the south, are gathered for exhibition, study, and publication at this scientific and administrative headquarters building. Five exhibition halls and a lecture hall occupy the ground floor. The other floors are devoted to administration, teaching, and research. The basement contains shops, photographic laboratories, and storage.

FIGURE 2. The storm beach of the 74-foot Faiyûm Lake (north of the ruins of ancient Philadelphia), containing Middle Paleolithic stone implements. Originating not later than Mousterian (Middle Paleolithic) times at a level of 112 feet above the sea, the Faiyûm Lake had sunk to 57 feet above sea level by Neolithic times. Later desiccation has lowered the lake to 147 feet below the sea.

PLATE 2

FIGURE 1. A drawing of an air perspective of the new headquarters building of the Sakkara expedition among the palms of Memphis.

FIGURE 2. Coffin texts and paintings on cedar planks forming the side of an ancient Egyptian coffin of about 2000 B. C. It is such texts as the above (lower right-hand portion of the plank), revealing early consciousness of moral responsibility, which the institute's coffin-texts project has copied from possibly 200 similar coffins scattered throughout the museums of Egypt and the Western world. Their publication will for the first time make available to scholars all the earlier sources of the Book of the Dead now known.

PLATE 3

FIGURE 1. Wreckage of the palace of Ramses III at Medinet Habu, flanked by his great mortuary temple. It is here that Professor Hoelscher has been carrying on excavations for the Oriental Institute and investigations of palace architecture. (See fig. 2.) The temple beyond the palace is some 500 feet long and is covered both inside and out with royal records, of which the epigraphic expedition of the institute, under Dr. Harold H. Nelson, is making facsimile copies. The work on the walls of this temple, the largest at Medinet Habu, is now approaching completion, and two folio volumes have been issued.

FIGURE 2. Hoelscher's reconstruction of a vaulted hall in the place at Medinet Habu. (See fig. 1.) This audience hall of Ramses III, built early in the twelfth century B. C., discloses for the first time, as noted by Professor Hoelscher, the fact that such a palace hall had a vaulted roof, with a higher vault over the central nave and lower vaults on each side—the fundamental roof type in later basilica and cathedral architecture.

PLATE 4

FIGURE 1. The new Oriental Institute headquarters in Egypt on the east bank of the Nile between modern Luxor and the great Temple of Karnak. The main building faces west and is surrounded by a large garden. The river bank to the west has had to be faced with stone, because the force of the current at flood time would otherwise undercut the institute's property. The main building on the right serves as a residence unit for the staff, while the library, drafting room, and offices are housed in the building on the left. Photographic laboratory, garage, shops, and servants' quarters are in detached buildings at the rear.

FIGURE 2. Air view of the ancient Babylonian city of Eshnunna, now called Tell Asmar. This ancient city is being excavated by the Iraq expedition, whose headquarters building, visible in this air view, has been constructed at the edge of the city ruins. The area cleared at the time this view was taken (January 23, 1931) is visible at the point of what looks like an arrow but is really the excavators' railway line terminating in the spreading dump at the outer end. The small "pockmarks" on the mound at the right of the excavated area were made by illicit native diggers before the institute received its concession to clear the mound. Photograph by courtesy of the Royal Air Force.

PLATE 5

FIGURE 1. Wooden post from a buried house of the Stone Age at Alishar. Eighty-five feet down in the great city mound of Alishar, the Anatolian expedition found the remains of a Neolithic (Late Stone Age) house. The walls seen in the photograph are the solidified débris of later buildings,

not the walls of the Stone Age house itself. The base of a fallen wall of the latter may be seen at the left. The roof of the house fell in thousands of years ago, but the stump of a wooden post which once supported the roof is shown here as it was found, still standing on its stone base.

FIGURE 2. Filming a corner of the palace terrace at Persepolis. This enormous terrace surrounded by a massive retaining wall, in places 50 feet high, contains about 150,000 square meters. The earliest palaces on the terrace were erected by Darius in the latter part of the sixth century B. C. and were followed by those of Xerxes and his successors. They were burned by Alexander the Great after his capture of the place in 330 B. C.

PLATE 6

FIGURE 1. The great Palestinian mound under which the famous fortress city of Armageddon (Megiddo) is buried. The expedition house is seen at the left. The top of the mound is about 13 acres in extent, and the accumulated rubbish of ancient ruins is 40 to 50 feet in depth. When the institute began work here, the mound was covered with growing grain cultivated by peasants such as are seen here in the foreground. The mound was then expropriated and purchased by the Palestine government with funds furnished by the Oriental Institute. The expedition of the institute has been at work here five years clearing and studying the successive strata of the ancient ruins.

FIGURE 2. Model of the stables of Solomon discovered by the Megiddo expedition. The condition of the ancient building as found is reproduced to scale at the right-hand end. The adjoining cross section of one of the stables discloses their interior arrangement. Rows of horses faced each other on either side of a central passage used by the grooms for feeding the horses. Two completely reconstructed stables are seen at the left. Part of Solomon's income was derived from his large-scale operations in horse trading. These were of sufficient interest to lead the Hebrew historians to refer to them in the Old Testament (I. Kings 9:15-19; II Chron. 1:14-17).

PLATE 7

FIGURE 1. Part of the Egyptian hall in the new Oriental Institute building at Chicago. In the background the exhibit of Assyrian sculpture begins with the great winged bull. These mysterious creatures were the "cherubim" of the Old Testament, so seriously misunderstood by later Christian art. The figure served as the sculptural embellishment forming one side of a palace gateway in the residence of Sargon II (eighth century B. C.) at Khorsabad. It is carved in calcareous stone similar to alabaster, is 16 feet high, and weighs 40 tons.

FIGURE 2. Sculptures on the front of the Oriental Institute building (designed by Ulric W. Ellerhusen, of New York City). This sculpture is a relief adorning the tympanum over the entrance door of the Oriental Institute building. It is intended to suggest the transition of civilization from the ancient Orient to the West. The East, on the left, is symbolized by the tall figure of an Egyptian scribe confronting the vigorous and aggressive figure of the West. The East carries over his right shoulder a palette and writing outfit, and the West has just received from him a tablet bearing an ancient hieroglyphic inscription suggestive of the transition of writing from the Orient to the West. This inscription, which reads "I have beheld thy beauty," is taken from a Fifth Dynasty temple inscrip-

tion. In the animals behind these two figures on either side the East is further symbolized by a lion and the West by a bison.

Behind the East are crowded the pyramids, the sphinx, the ruins of Persepolis, and a group of six great oriental leaders. Beginning with the foremost in the top row, the leaders are: Zoser of Egypt, the first great builder; Hammurapi of Babylonia, the first great lawgiver; Thutmose III of Egypt, the first empire builder; Ashurbanipal of Assyria, who collected the first great library; Darius, the great organizer; and Chosroes of Persia.

Behind the West on the right are the Parthenon, a European cathedral, and a modern skyscraper tower. The six heads represent Herodotus, Alexander the Great, Julius Caesar, a crusader, a modern excavator leaning on his spade, and a modern archeologist at work with his lens. In the center, over all, shines the oriental sun, its rays ending in human hands.

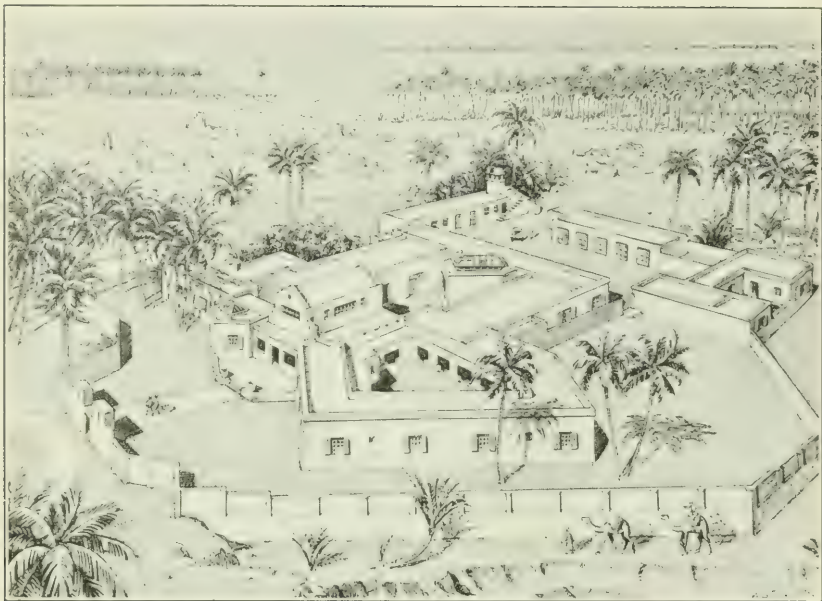


1. THE NEW ORIENTAL INSTITUTE BUILDING AT THE UNIVERSITY OF CHICAGO
SEEN FROM THE NORTHWEST

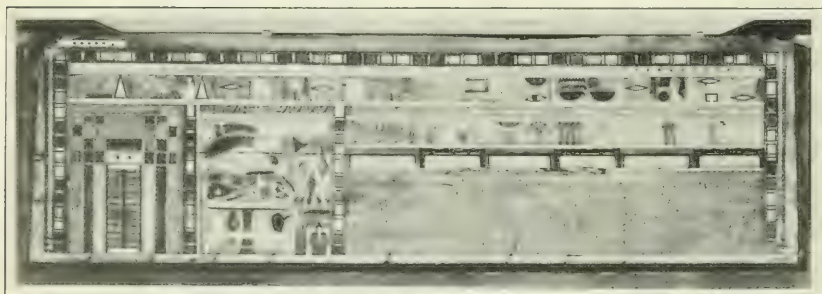


2. STORM BEACH OF THE 74-FOOT FAIYUM LAKE

It contains Middle Paleolithic Stone implements. (North of the ruins of ancient Philadelphia.)

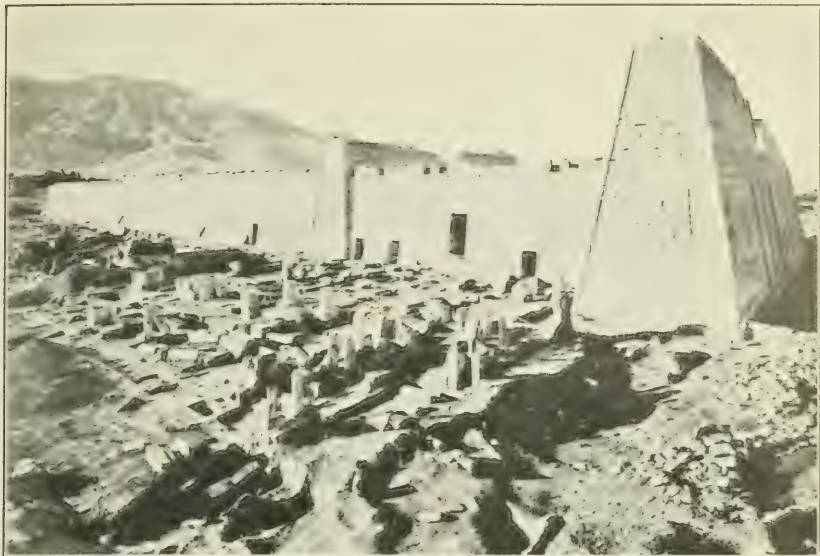


1. DRAWING OF AN AIR PERSPECTIVE OF THE NEW HEADQUARTERS BUILDING OF THE SAKKARA EXPEDITION, AMONG THE PALMS OF MEMPHIS

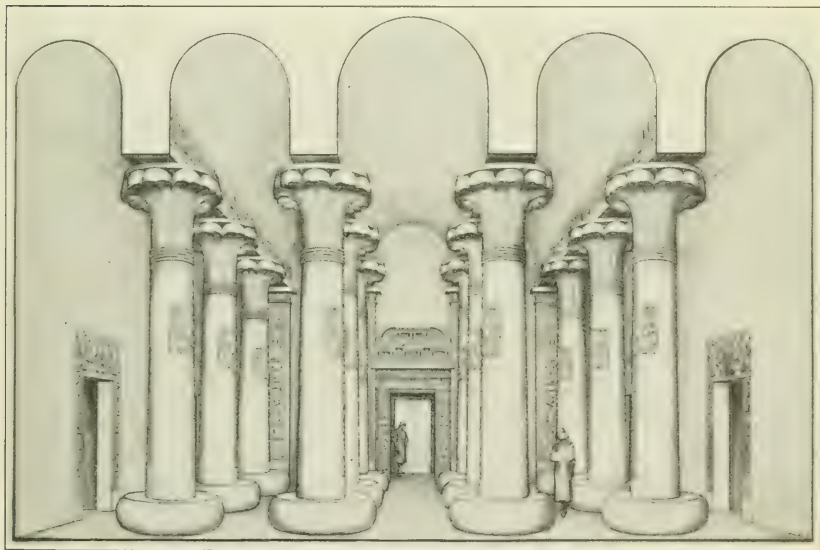


2. COFFIN TEXTS AND PAINTINGS ON CEDAR PLANKS FORMING THE SIDE OF AN ANCIENT EGYPTIAN COFFIN OF ABOUT 2000 B. C.

Inside view.



1. WRECKAGE OF THE PALACE OF RAMESES III AT MEDINET HABU, FLANKED BY HIS GREAT MORTUARY TEMPLE

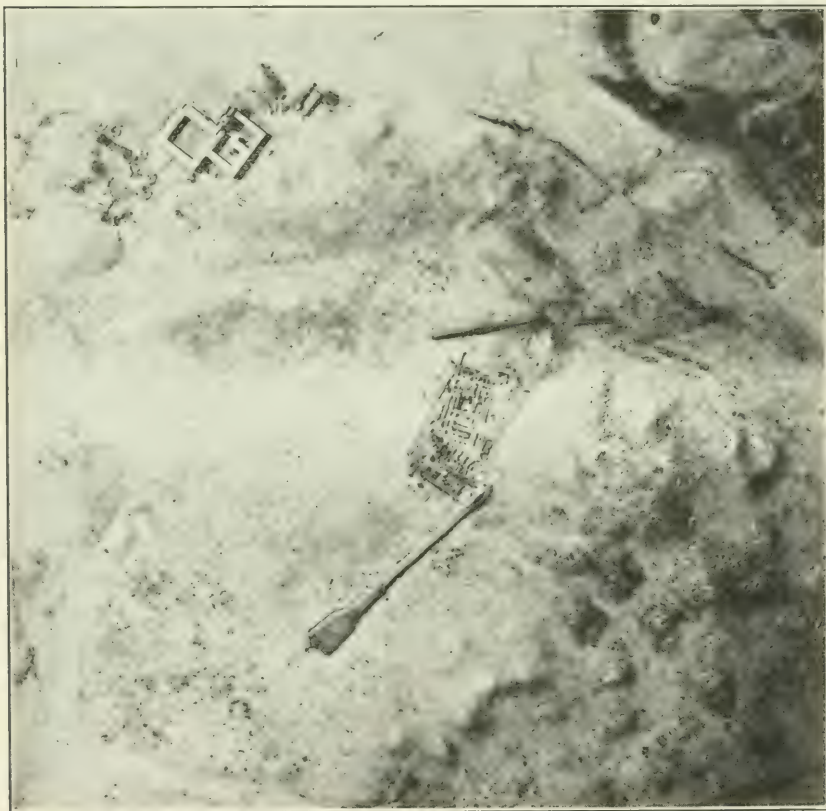


2. HOELSCHER'S RECONSTRUCTION OF A VAULTED HALL IN THE PALACE AT MEDINET HABU

(See fig. 1.)



1. THE NEW ORIENTAL HEADQUARTERS IN EGYPT ON THE EAST BANK OF THE NILE BETWEEN MODERN LUXOR AND THE GREAT TEMPLE OF KARNAK



2. AIR VIEW OF THE ANCIENT BABYLONIAN CITY OF ESHNUNNA, NOW CALLED TEL ASMAR



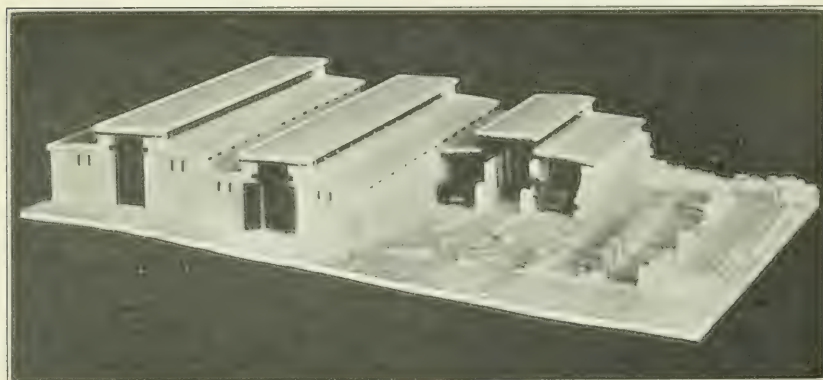
1. WOODEN POST FROM A BURIED HOUSE OF THE NEW STONE AGE (NEOLITHIC)
AT ALISHAR



2. FILMING A CORNER OF THE PALACE TERRACE AT PERSEPOLIS



1. THE GREAT PALESTINIAN MOUND UNDER WHICH THE FAMOUS FORTRESS CITY OF ARMEGEDDON (MEGIDDO) IS BURIED



2. MODEL OF THE STABLES OF SOLOMON DISCOVERED BY THE MEGIDDO EXPEDITION



1. PART OF THE EGYPTIAN HALL IN THE NEW ORIENTAL INSTITUTE BUILDING
AT CHICAGO

The Winged Bull marks the beginning of the Assyrian Hall opening on the right.



2. SCULPTURES ON THE FRONT OF THE ORIENTAL INSTITUTE BUILDING
Designed by Ulric W. Ellerhusen of New York City.

MOHENJO-DARO AND THE ANCIENT CIVILIZATION OF THE INDUS VALLEY ¹

By DOROTHY MACKAY

[With 4 plates]

In all the wealth of archeological discovery since the war, three finds of supreme interest stand out: The tomb of Tutankhamen, the royal graves at Ur, and the ancient Indus Valley civilization.

The importance of the tomb of Tutankhamen lies not so much in what it has contributed to our previously considerable knowledge of that period of Egyptian history as in the world-wide interest that its wonderful art and wealth aroused in the work of the excavator, hitherto apt to remain unknown to all but the interested few. To that spectacular find, the other two discoveries might almost be said to be due; for public interest means funds, and without ample funds digging up a dead city or clearing temples or tombs from enshrouding débris of the ages is too costly a business to be lightly undertaken.

The royal graves at Ur have not only yielded up objects of a remarkable and before then unknown art and technique; they have also revealed an extraordinary and scarcely believable savagery in the ritual of the grave. That such moral backwardness should have been coupled with such beauty of conception in the realm of art has been something of a shock to a world in which, more and more, respect for human life and happiness tends to surpass in its development artistry of form and expression.

The third of these discoveries, though still shrouded in a veil of mystery which the careful excavations of the last nine years have only partially removed, may ultimately prove to be the most important. For it will clearly bring to bear on the whole history of early races and religions a revealing light whose rays will penetrate far beyond the limited area of the one river valley and even of India.

Of the religions and philosophy of India, its races in pre-Aryan times and now, this pushing back of history through some two

¹ Reprinted, with slight changes in text and illustrations, by permission from Asia, vol. 33, No. 3, March, 1932.

millenia is bound to add enormously to our knowledge and understanding. But also the races, religions, and arts of ancient Baluchistan, of Sumer and Elam, and of other countries still farther afield come into this new circle of illumination. For bit by bit, item by item, the Indus Valley finds, in conjunction with those of Sumer and elsewhere, are revealing the close knowledge that the ancient peoples of Western Asia had of each other. Indeed, they appear to have traveled from place to place and traded together in a manner that the modern world, accustomed to train and car and airplane, can hardly credit to those who had none of these things, but were dependent on animal transport, primitive wagons, and sail.

In the various cities of Sumer, notably, at Kish, Ur, and Lagash, seals lost by merchants from the Indus Valley have been found by the excavator well-nigh 50 centuries later. Seals of Sumerian workmanship have been unearthed in the north of Syria; and there is evidence that the Sumerians had a trading colony in Asia Minor. In recent years, moreover, other objects than seals, which betray Elamitic, Babylonian, and possibly early Indian influence also, have been found from ancient Egypt on the one hand to as far north as the Caspian Sea on the other.

The archeological study of the ancient world is rapidly breaking down artificial barriers between culture and culture, and the histories of race and race; so that for a proper understanding of the story of the early world, one needs to be more than an Egyptologist only, or Assyriologist, or Sanskrit scholar. Wide flung were the cultures and interrelationships of the ancient peoples of the world; broad in outlook must be our studies of them.

Before the discovery of Mohenjo-daro, the history of India seemed to begin with the coming of the Aryans, which appears to have taken place during the latter part of the second millenium B. C. But little was known of the Neolithic age, save for a few finds of flint implements and the dolmen burials in southern India; and the rough cyclopean walls at Rajagriha in Bihar, which are relics of a high antiquity. The Aryans themselves were apparently seminomadic people and unaccustomed to the occupation of dwelling houses. The only material monuments that can be safely ascribed to their early years in India are the burial mounds of Lauriya Nandargarh in Bihar, which are tentatively dated to the seventh or eighth century B. C. Their first buildings were probably of wood, a supposition to which support is lent by the obvious imitation of wooden structures in the earliest stone buildings of India, chief among which are the Buddhist *stūpas* and monasteries. The greatest monuments of the early Aryans are, in fact, purely literary—the hymns of the Rigveda, Brahmanas, Puranas, and other Sanskrit writings.

In 1923, the veil which concealed the India of pre-Aryan days was suddenly lifted in a dramatic and completely unforeseen manner. A ruined Buddhist *stūpa* had for some time been known in the Larkana district of Sindh. Alone in a dreary jungle of dusty tamarisk and stunted thorn trees, it raised its battered head, a prominent landmark, some 72 feet high, in a land of exceeding flatness. The late R. D. Banerji, of the Archaeological Survey of India, on examining it found that it stood upon a mound composed entirely of burnt brick and mud filling. The bricks of the *stūpa* corresponded in size with the bricks of the mound, and to ascertain the nature of the supposedly Buddhist buildings beneath the *stūpa*, Mr. Banerji cut down into them. He came upon a number of the square stamp seals and copper amuletic tablets—quite clearly not Buddhist—that have since come to be recognized as the most characteristic of the smaller objects produced by the Indus Valley culture of about three millenia B. C.

He and Sir John Marshall, then director general of the Archaeological Survey of India, immediately realized that here were the remains of a civilization whose existence had hitherto been little more than dimly suspected—a few similar seals had been unearthed two years before at Harappa, about 450 miles distant, on the old bed of the Ravi River in the Montgomery district of the Punjab. This site, which appears to have been an even larger and more important city than Mohenjo-daro, lies not so far removed from the beaten track, and it had, unfortunately, served at one time as a quarry for railway ballast.

After a further examination of the new-found site, Sir John Marshall published a preliminary account of it in the Illustrated London News (Sept. 20, 1924), which immediately attracted keen attention. A number of similar square stamp seals, bearing the same pictographic script and animal devices, whose source had hitherto been a mystery though they were found in Sumer and Elam, were at once "re-excavated" from the Louvre, Paris, and elsewhere; and many similarities between the cultures of Sumer and the Indus valley were noted. Mr. E. Mackay, at that time field director of the joint Oxford and Field Museum (Chicago) expedition at Kish, had shortly before unearthed one from among the foundations of a temple of Sargonic date, where it had apparently been thrown in unnoticed with the earth filling. He showed it to the late Miss Gertrude Bell, honorary director of antiquities in Iraq, and a cast of it was sent to India for comparison. The new-found civilization was, accordingly, tentatively named the "Indo-Sumerian" civilization of the Indus valley, and, from the Kish find, dated provisionally to the beginning of the third millenium B. C.

The Government of India thereupon decided to concentrate on the thorough excavation of Mohenjo-daro and, on a smaller scale, of Harappa, and the work at the former site has for the past five winter seasons been intrusted to Mr. Mackay, who came to it from Kish. A recently published 3-volume book, *Mohenjo-daro and the Indus Civilization* (168 plates), edited by Sir John Marshall,² deals exhaustively with the discoveries up to 1927. A further large book by Mr. Mackay, on the many new discoveries since that year will shortly appear.

The unraveling of this mystery of the past has, unfortunately, been very heavily handicapped by the fact that the people of Mohenjo-daro and the companion cities wrote upon some perishable material, such as wood, or bark, or parchment. The finding of their seals as far afield as the Sumerian cities shows them to have been great traders, and they must have developed a system of receipts, contracts, and other commercial documents on the same lines as did the Sumerian merchants of Ur. There is abundant evidence, too, that the city was excellently administered and that litigation was developed among its citizens; legal documents must also have been customary. But all have disappeared, destroyed by the dampness and salty nature of the soil.

The pictographic characters upon the many hundreds of seals that have been found unfortunately hardly take us anywhere in the decipherment of the language. They most probably give the names of the owners of the seals, with perhaps a title here and there. A careful compilation of the various characters on the seals shows, however, that well over 300 were in use; the language was not an alphabetic one, but syllabic. But without any inscriptions long enough to give inflections and verbal forms there is at present little hope of working out this ancient language of the Indus Valley. Possibly, however, further finds in Iraq may come to the student's aid. The Sumerians, and the Assyrians and Babylonians after them, seem to have taken an interest in drawing up sign lists and compiling grammatical forms. There is a chance that one day a tablet may be discovered with the Sumerian equivalents of the Indus Valley pictographs. Then it might be possible to identify the cities of the Indus Valley with at present unidentified places with which the Sumerians were wont to trade. For Mohenjo-daro is merely the modern local name, "Place of the Dead"; of neither that city nor Harappa do we know the name used by the inhabitants.

In the same way that the absence of inscriptions rules out the possibility of drawing up any "history" of the Indus Valley during

² *Mohenjo-daro and the Indus Civilization*, edited by Sir John Marshall. 3 vols., 164 pls. Published by Arthur Probsthain, London, 1932.

the fourth and third millenia B. C.—and here a not unnatural envy of the comparative ease with which it is possible to give a story of the vicissitudes of Ur must be admitted—the absence of wall decorations makes the picturing of contemporary life less easy than elsewhere; it is a matter of slowly piecing together minute bits of evidence. The people of Mohenjo-daro were not artists in the sense that they wished to surround themselves with beauty and adornment. From the paintings and sculptures on the tomb, and temple, and palace walls of Egypt, a great deal has been learned about their religious and domestic life, and of their arts and crafts, even to the making of bread and of wine; the goldsmith, the basket weaver, the ropemaker all ply their trades before our eyes. In Sumer, Assyria, and Babylonia we see the life of the times portrayed in inlay, or sculptures, or colored tiles. The farmer of the Tell al 'Ubaid inlay milks his cow from behind; the king of Kish drives his prisoners before him; we see Ur-Nammu carrying his basket of bricks to build the temple tower at the Moon god's command; and the Assyrian monarch hunts or storms his enemy's defenses and flays him after defeating him in battle.

All this information we miss in the Indus Valley cities; nor is one justified in assuming that wall decorations once existed, but have perished. Traces there are here and there of plaster upon the walls, but quite insignificant; nor do they show any signs of having been adorned with anything more than roughly executed bands of color. Inlay there is, but almost solely geometrical in design and clearly used for the ornamentation of boxes and furniture rather than of walls. Sculpture is represented among the finds, but confined to crudely carved statues; in stone working there is nothing approaching the artistry and skill of execution of the mural scenes of Egypt and Assyria, save the engraving of the seals. The art of glazing was practiced in the Indus Valley; but it was only applied to the manufacture of small articles of personal adornment, pieces of inlay, and model animals.

Yet, for all this lack of direct assistance on the part of the dwellers in Mohenjo-daro, it has been possible to build up a quite vivid picture of their everyday life, their religion, occupations, and surroundings. And there is always the hope of some unexpected find to buoy up the excavator at his work. He never knows what the day may bring forth from Pandora's box of secrets.

At the zenith of its prosperity, Mohenjo-daro was clearly a large and important place. Its massive public buildings and solid, comfortable houses covered about a square mile—all made exclusively of burnt brick, save where mud-brick fillings served to make high platforms of the ruined older buildings, on which to raise the later ones

above the level of the oft-recurring floods. Streets and open spaces there were, carefully planned out so that the buildings form rectangular blocks; and there is evidence that by-laws existed whose observance was enforced. To the sanitation of the city a degree of attention was paid that is surprising, and to the elaborate drainage system further reference will be made.

Of the outskirts of the city, our knowledge is at present somewhat dim. No walls and fortifications had been definitely located when the book on the excavations up to 1927 was written. The remains of city walls would now lie almost wholly buried beneath the thick deposit of alluvium that the Indus has spread over all its valley in the course of the ages. Their burnt-brick facings would in any case have served as "brick mines" for near-by villages of later days, as the vast ruins of Babylon have done. On the other hand, the walls of Mohenjo-daro may not have been built on any very massive scale. There is a curious lack of evidence of the raiding and destruction to which most cities of those days seem to have been subjected. There are no quarters of the city as yet excavated which were systematically destroyed by fire; nor is there a great variety or quantity of weapons found. A few spearheads, blade axes, mace heads, and sling balls have been found, but all these may have served more peaceful purposes, or have been used for protection against brigands, as are the axes which the Sindhis of to-day carry about with them in the jungle paths. The modern Sindhi also shoots clay pellets from a bow to protect his crops from marauding birds.

Though in cutting a well, masonry has been found at a depth of some 26 feet below the general level of the plain, so that it is hard to tell how far out from the present mounds earlier occupations of the city extended, it is possible to delimit the latest city by the presence of brick fields which must have lain outside the dwelling quarters. These lie chiefly to the northeast and southeast of the city, which implies that the prevailing winds, then as now, were westerly. Potters' kilns, too, lay nearer in to the center of the mounds in the latest period of the city's occupation. Indeed, in view also of the fact that the masonry of the latest levels is markedly inferior to that of the deeper earlier strata, it is clear that a definite dwindling in both size and importance had set in before the city was finally abandoned.

Why the city should have been abandoned it is hard to say. There are many possible reasons—flood, pestilence, or the attacks of enemies; or the river may suddenly have changed its course and left the city cut off from communication with the other cities of India, and elsewhere, with which it had been wont to trade. There are arguments for or against all these reasons, but the sum of the evi-

dence points to floods being at all events the predisposing cause of the population going elsewhere.

The evidence that the city suffered very badly from the devastating effect of floods and that the inhabitants lived in constant dread of them is overwhelming. Wherever you walk in the excavated streets and lanes, you see walls that lean precariously—the tops of some have had to be removed lest they fall upon the diggers at their work—and others which have sunk, so that the courses of the bricks wave up and down. Quite often, indeed, when a house fell into ruin its walls were filled up with mud brick to make a platform, on which the new house would be moderately secure from flooding. Yet oft-times the water penetrated into these artificial platforms, especially where there was any admixture of the rubble of broken brick and potsherds, of which so much is seen in the latest strata of the city.

If one pictures the people of Mohenjo-daro as dependent only on their fields for supplies, the annual floods from the Indus would have been a veritable godsend to them, bringing the fertilizing silt for the wheat, which the examination of carbonized grains found in the ruins has proved them to have grown, as well as for other crops. But they were also traders, as their seals bear witness; and to be isolated even for a short period would have proved disastrous. In years of exceptional flood they were probably driven, as are the people of the two modern Sindhi towns, Shikarpur and Larkana, from time to time, to leave their city and take refuge temporarily elsewhere. To such evacuations of the city perhaps may be ascribed the two great breaks in the continuity of occupation which are apparent. Merely the threat of such an upheaval a few times within a short space of years would have sufficiently urged a change of site.

Again, the river may have shifted its bed, as it did in the summer of 1927, when from a distance of over 4 miles away it came to within 3 miles of the ruins. The blow that it would have been to the city's trade, if the river had suddenly left its quays—for the Indus, or a branch of it, seems to have flowed beside the city in the days of its prosperity—can be imagined. Ur and other Sumerian cities met with that fate and fell.

Pestilence may also have been a contributory cause of the fall of Mohenjo-daro. It is a settled policy in India to-day that a village stricken with plague is temporarily abandoned; and if most of its inhabitants fall victims to the disease, which they may take away with them, the village is perhaps never reinhabited. The hoards of jewelry, and copper and bronze tools and weapons that have been found below floor level strongly suggest that their owners buried them for safety during a temporary absence, but never returned to retrieve them.

It is a curious feature of Mohenjo-daro that there is very little available evidence as to the method of disposal of the dead. If burial was the custom, the cemeteries must now lie many feet below the thick riverine deposit of silt; and their discovery in such a large area must be mainly a matter of chance. Or cremation may have been practiced, and the remaining bones and ashes scattered in the river, as you see done in India to-day. There is some evidence at Harappa of the practice of cremation, and ashes have been found in various large pots at Mohenjo-daro together with small cups and other objects. But no definitely human bones have been recovered from these pots, save in a few isolated cases (the so-called fractional burials, because only part of the skeleton is present), and it is open to belief that the majority of these jars were merely receptacles for household rubbish.

A certain number of skeletons have been found at Mohenjo-daro. But of those unearthed in the earlier excavations and included in the recently published book, only 15 can be regarded, from the circumstances in which they were found and the associated objects, as contemporaneous with the city. The remainder may have been squatters in the ruins at any time within a century or two after its abandonment, or even later than that. Of the 15, 14 lay in a strange variety of attitudes in one single room, a circumstance that itself gives pause to any that would deduce the racial elements of the population from those few bones. The very fact that these skeletons were together in one room, whereas the remains of the rest of the large population are conspicuously absent, suggests that they may have been a group of slaves or prisoners who died in captivity of some sudden pestilence and were hastily covered over where they lay instead of undergoing the customary burial or cremation rites. Indeed, the fact that these skeletons represent more than one race is in favor of their being foreigners, whether prisoners or slaves. Of a number of skeletons more recently unearthed at Harappa, the associated pottery and other circumstances make it probable that they date from some time later than the final abandonment of Mohenjo-daro.

Until, then, a great many more skeletons are unearthed at both sites, it would be unjustifiable to draw any definite conclusions from anthropometrical evidence as to the race that formed the predominant element in the Indus Valley at that time.

A study of the sculpture does not help very much, for though there are features common to the few statue heads that have been found, such as an extraordinarily low forehead and small cranium and a tendency to narrowness and obliquity of the eyes, there are other features that are entirely due to the lack of skill of the sculptors, such

as a saucerlike ear with a central hole. One must then be content to wait the finding of a cemetery or some other more definite evidence before speculating too closely on the race that inhabited these ancient cities.

Concerning the religion of the Indus Valley people, we find ourselves on rather surer ground. For though there are so few statue heads in stone, the large number of the terra-cotta female figurines that have been found—mostly too well made to be children's toys, and all alike in dress and headdress—suggests that a mother-goddess was worshiped. Her figure may have stood in its little shrine in every house. This mother-goddess, if so she be, invariably wears a wide girdle and several necklaces of beads, represented by pellets of clay stuck on before the figurine was baked. Of her headdress, it may be said that if that of Queen Shub-ad of Ur was strange and complicated with its ribbons of gold, and beads, and lofty comb, the mother-goddess of Mohenjo-daro had just as strange a one. On either side of the head was a pannier held in place by a broad fillet round the brows; above stood a lofty fan-shaped arrangement, and, in addition, a curious conical, hornlike projection hung down in front of each ear. This mother-goddess may quite possibly be one with the goddess already familiar to us as Ninkharsag of Sumer, Ishtar of Babylon, Astarte, Isis, Aphrodite, and Venus of the later religions of the early East, and Greece, and Rome.

But there were also typically Indian features in the religion of the ancient Indus Valley. On one of the earliest seals found there is a seated four-faced figure with legs in the yogi-like posture associated with the state of contemplation. Around him stand four beasts—the bull, the elephant, buffalo, and rhinoceros; and it is impossible to avoid the conclusion that Śiva was worshiped in the aspect of Paśupati, Lord of Beasts.

An animal of some kind also occupies the place of importance in the middle of each of the square stamp seals, with very few exceptions: The so-called unicorn, the short-horned and Brāhmāni bulls, the elephant, tiger, buffalo, rhinoceros, fish-eating crocodile, or some mythical beast. In many cases, some kind of cult object is associated with the animal, which suggests that the gods of the Indus Valley were worshiped in the aspect of some animal, as was Isis in the form of the cow in ancient Egypt. On a small prism-shaped sealing of pottery the cult object associated with the unicorn is even seen carried on a pole by one of four men in procession, just as were the "nome" ensigns of early Egypt. Clearly, then, a regular pantheon of gods was worshiped in India before the coming of the Aryans, to which can be traced several features of the Hindu religion of to-day.

In addition to the pottery figurines of the mother-goddess, enormous numbers of model animals are found, some obviously no more than children's toys, and often so roughly made as to have been the handiwork of the children themselves. But some are better made, especially several bulls whose modeling is really very striking in its spirit and efficiency; and these were very probably votive figures associated with the religious ideas outlined above.

By far the most arresting, however, of the statues and figurines so far unearthed is one of cast bronze—a dancing girl, posed in most realistic attitude, with scornful mien, and quite unforgettable in faithfulness of representation.

But the seals are unquestionably the most striking feature of the small finds. Made of steatite, white, gray, or black, they are mostly square in shape, with a divided boss upon the back, through a hole in which a cord was passed, so that the seal could be worn at neck or wrist. Oblong seals, with curved back and flat obverse bearing a row of pictographic characters, and perforated from side to side, are also found in considerable numbers; and, more rarely, small square stamp seals with geometrical designs. The uniformity of design of the typical square stamp seal—the line of pictographs above the animal, the cult-sign—is only paralleled by the uniformity of style throughout the whole period during which the city was occupied. And it seems likely that, although the city was rebuilt and re-occupied several times, its total duration was not long enough to allow of much change in the mode of writing or the accepted canons of art.

Of the animal devices, the so-called unicorn was by far the most popular. It is a strange beast, rather bull-like in body; and there is the possibility that the one horn really represents two, one hiding the other. The mangerlike cult object before it appears to have been made of basket work—as are many of the mangers in the modern villages round about the ancient site—or of leather work, but why there should be upper and lower parts to it remains, for the present, a mystery. Other animals especially favored were the short-horned and Brahmani bulls. The frequent appearance of the elephant, rhinoceros, and tiger suggests that there was a rather larger rainfall in ancient Sind than now, for they are forest-loving animals and at present quite unknown in the Indus Valley. It is noticeable also that the lion, a denizen of dry open country, has never yet been found upon a seal, though these animals still exist in Kathiawar to the south of Sind.

It is on the seals that the dating of Mohenjo-daro largely depends; though there is ample evidence from the close similarities between large numbers of the small objects found in the three cities, from

the style of and motifs on the painted pottery, from architectural features, and so on, that the later levels of Mohenjo-daro are practically contemporaneous with the earlier levels of Ur and Kish. In addition to the seal found by Mr. Mackay at Kish, which establishes the pre-Sargonic date of the Indus civilization, i. e., prior to about 2750 B. C., Mr. Woolley has found two other seals of Indian origin at Ur. One of these appears to have belonged to an enterprising merchant from one of the Indus Valley cities, who realized that his customers in Sumer could not read his name as written. He accordingly had it engraved in cuneiform characters which are quite definitely in the style of about 3000 B. C. And not only his clients, but archeologists of 5,000 years later have reason to be grateful to him.

In the maze of buildings that have been excavated, those that first catch the eye are naturally the Buddhist *stūpa* and its surrounding monastic buildings. Raised high above the level of the wide alluvial plain, they must have presented a striking landmark when at their zenith. The umbrella that in those days would have crowned the *stūpa* was very probably gilded over, and dazzling would it have been in the brilliant sunshine of Sind. Even now that the umbrella and the dome beneath it exist no longer, the ruined mud-brick drum is seen from miles around.

These Buddhist buildings, though made of bricks baked by the original inhabitants of the ancient city, are well-nigh 3,000 years more recent in date, for a pot full of coins of King Vasudeva (185–220 A. D.) of the Kushān Dynasty has been unearthed in one of the monk's cells.

The most striking of the public buildings of the early city itself marks an interesting departure from the temples and palaces of the ancient sites that have been excavated in other countries of the East. It is an imposing structure built around a great tank—entirely of burnt brick, well and truly laid. Indeed, the masonry would reflect high credit on the modern builder with the closeness of its joints and the smoothness, due to rubbing down, of the walls and floor of the tank. The latter measures 39 feet long by 23 feet wide, and the water was entered by flights of steps at its northern and southern ends. These steps appear to have been covered with wood, for there are slots at either end of each tread to take the ends of planks; and it is not unlikely that thin sheet copper was laid over the wood. The tank itself was rendered water-tight by a thick puddling of clay between two thicknesses of its walls, and also—a refinement that speaks volumes for the advanced stage of that ancient civilization—a layer of bitumen, which is still to be seen.

Surrounding the tank was a wide platform, at the back of which fenestrations in the walls led to a number of rooms of different

sizes and shapes, whose uses can only be surmised. The remarkable thickness of the outer walls of this great building, whose external faces have a pronounced inward slope like the containing walls of the Egyptian temples, strongly suggests that there were other rooms above, possibly opening onto a gallery round the tank. The latter was probably open to the sky, though perhaps it was covered by an awning.

The purpose of this very unusual building was in all probability religious; as in modern India, it was perhaps customary to perform ablutions before entering the temples of the gods. The great tank building is close beside the *stūpa* mound; and it is not unlikely that the mass of ruins on which the Buddhists built their *stūpa*—the highest mound of the ancient city—was once itself a temple. For all through the history of the world sacred places have tended to retain their sanctity from generation to generation.

Though as yet no building that can definitely be said to be a temple has been cleared, among the number that are obviously not dwelling houses there are several that might be, if only the characteristics of a temple of those days in the Indus Valley were known. Of images that might be those of deities, however, none have been found complete, save a somewhat battered, crouched figure of a man, whose mouth is apparently wide open as if to sing or shout.

It has been suggested that the great tank may have been used for keeping sacred fish, or even crocodiles, as in the precincts of various temples and shrines in India to-day; but the available evidence is in favor of its having been used for ablutions. For it is one of the most remarkable features of Mohenjo-daro that personal cleanliness was clearly something of a fetish: To every house its ablution pavement with but few exceptions—a well-paved floor, where water was poured over the body from a water jar, sloping gently to one corner, whence a drain hole through the outer wall of the house carried away the water into the street drain without. In the poorer quarters, the water ran into a big earthenware jar outside, from which it percolated away into the soil, leaving any solid matter to be removed by the city's scavengers.

In the main streets, the drainage system can only be described as elaborate; it marks a high degree of civilization. Well-laid brick channels run down either side of each of the wider streets, receiving tributaries from the narrower lanes at right angles, and also the outflows from the houses. These drains did not lie open, as do the channels in many parts of the modern towns of Sindh. They were covered over with bricks, laid flat, on edge, pentroofwise, or at a slant. The particularly large and deep street drains in the vicinity of the great tank building were roofed with big blocks of stone, that

were probably brought by river from Sukkur, some 56 miles distant, the nearest spot at which such stone is obtainable. We can imagine that periodically the streets of Mohenjo-daro were "up" for the cleaning and repair of the drains beneath their surface. And it is a quaint commentary on the persistence of human traits that here and there a contractor substituted a covering of brick for the more valuable stone before reburying the section of drain to which he had to attend.

In three places in the city so far excavated, there are drains of exceptional size and importance. They are corbel-roofed, for the inhabitants of the Indus Valley in those days seem to have been ignorant of the true arch, though they used wedge-shaped bricks for lining their wells; they were high enough for a man to walk through them in a crouched position; and they had small channels in their floors that look quite adequate in themselves to take the drainage from buildings of ordinary size.

One of these culverts served to drain the great tank; but as the opening through which the water ran out to this drain measures not more than a foot each way, so that it would easily have been carried away by the channel in the floor, one is led to ask what might have been the purpose of the big vaulted passage, roofed over and with a manhole for someone to descend from above to clean it out. There is the companion question to be answered: How was the great tank filled? There is a large well in one of the eastern rooms of the building, but there is no channel from it to fill the tank, nor evidence of any mechanical device by which sufficient water could be supplied from it. It has been suggested by Mr. Mackay that after the tank was emptied the culvert was cleaned out by a man who descended through the manhole; that the outflow at the far end was then closed; and that the culvert was filled up from a canal by some such means as the Persian water wheel or a *shadûf*. If the culvert were filled to its roof through a length that would bring it to the nearest point where it could have reached a canal or branch of the river, the water that ran back through the drain-hole into the tank would have filled the latter to the depth of some 5 feet. Unfortunately, the culvert has been destroyed at the further end, partly by the Buddhist monks in the quest for brick, and partly by the hand of time. And definite proof that the inhabitants of the city were possessed of so high a degree of imagination and ingenuity so early in the history of man is lost.

The majority of the street drains ran into soak or sediment pits. In the former, the floors of the pits were unpaved, so that the water percolated away into the soil. The mud that was left was cleared out by scavengers, for whose use there were footholds that still remain

in the sides of some of the pits. In the sediment pits, on the other hand, the floor was of brick, and the surplus water ran off through an outflow near the top after depositing its solid contents. It has not been possible to trace the ultimate destination of the larger street drains on the outside of the city, owing to the denudation by time and weather of the outer slopes of the mounds.

It is probable that it was mostly water from the bathrooms and rainwater from the roof that was carried off by this elaborate system; but there is evidence in certain parts of the city, at all events in the later periods that suggests that sewage also ran down from holes in the walls of upper stories or from the roofs, as in modern Sindhi towns, where it is seen trickling down the walls in the poorer, and even in the not so poor quarters. As each house of any importance had its own well, it is difficult to avoid the conclusion that percolation from the soak pits and drainage jars of the poorer quarters must have given rise to epidemics of disease from time to time, despite the excellent drainage of the more spacious streets and houses.

Let us now look into a typical dwelling house to see how the people lived. To enter it, you must turn into a side lane, for there were practically no doors opening on to the main streets, save those of public buildings. As elsewhere in the modern East, no man made outward display of his wealth, and the ground floor of his house presented a frontage blank of doors and windows to the public gaze. Inside there was usually a courtyard—mostly rather small, and to one side of the building—in which there was a well. It appears that often a householder would give access to his well to his neighbors also, in which case it was secluded from the rest of the courtyard by an enclosing wall. And the brick benches beside some of these wells and the deep pot marks in the floors bespeak a hearty interchange of the latest news of the town.

There was probably at least one upper story, for not only were the outer walls of the dwelling houses extraordinarily thick and, moreover, sloped inward on the outer face to give greater strength, but there are one or two stairways that even now have landings and probably did not lead solely to the roof. Outside stairways, of which there are several examples, may perhaps indicate that more than one family lived in the same building, occupying different floors. This seems all the more probable when you see two drains closely side by side, one from the ground floor and the other running down in the thickness of the wall.

The houses can scarcely have been well lit, for what few windows there were seem to have been little more than ventilators set high in the wall. But in a land of such blazing sunlight and heat, large windows are rarely made. As said before, nothing was done to

beautify the dwelling rooms, unless embroidered hangings took the place of the sculptures and paintings and inlay work of the other peoples of those days. Hangings, whether of cotton material or wool, would inevitably have perished, leaving no trace behind. One tiny piece of cotton fabric that had most fortunately survived, embedded in and preserved by the patina on a silver jar, proved on microscopical examination to be true cotton—the first known in the history of the world.

Cooking was done, as by the Sindhi woman of to-day, over little fires of brushwood between brick supports for the cooking vessels; of the latter many are found, both in pottery and copper. Grinding stones, pestles and mortars, and strainers there are in plenty; and little dishes divided into four compartments probably served as cruets. Spoons were cut from shells of varying sizes and have a strange 1-sided shape, which, curiously enough, was afterwards copied in pottery. Beef, mutton, pork, fish, and even turtle and the flesh of the fish-eating crocodile served as food, according to the evidence of rubbish piles and household refuse jars. And flint knives were struck as required from large flint cores, save in the larger houses where copper knives had already come into use.

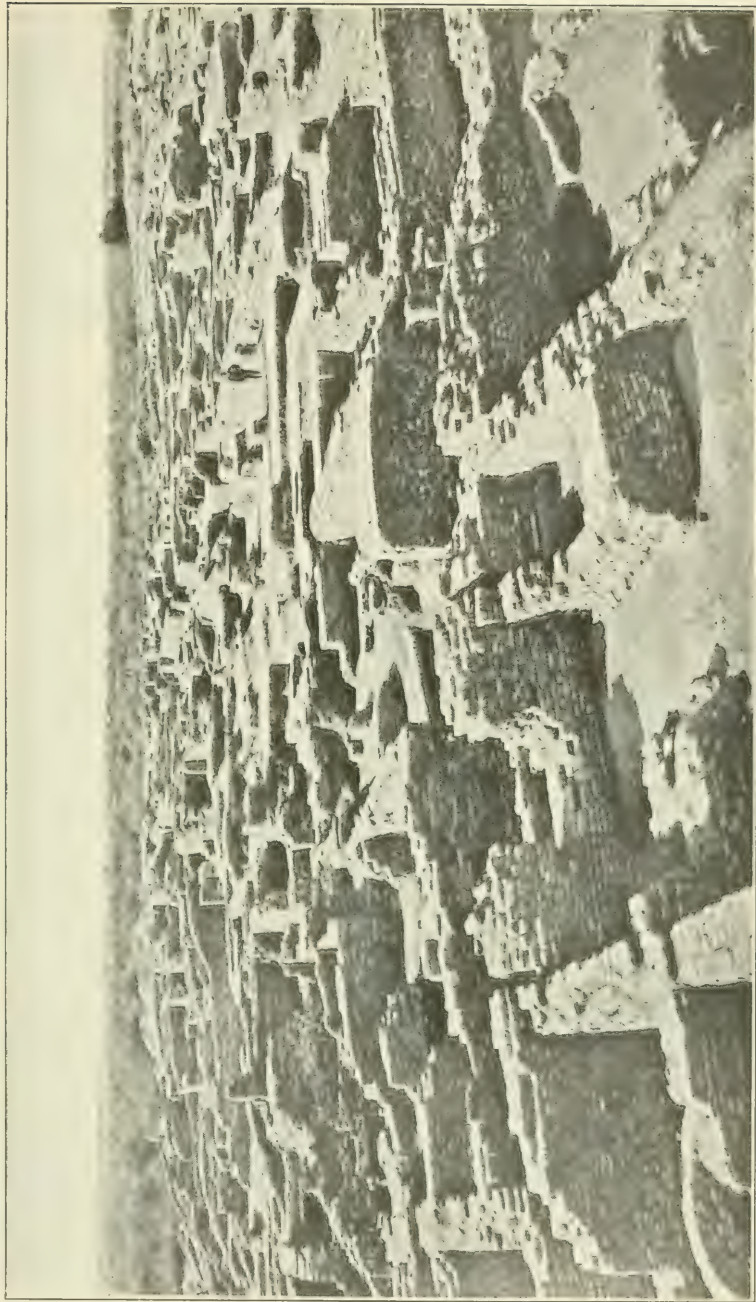
Grain and other foodstuffs were kept in huge pottery jars that remind one of the story of Ali Baba; they were probably set in wooden stands, and often in brick-lined depressions in the floors, to keep them upright, for none of them have a stable base and many are actually pointed below. Clothing, too, may have been stored in these jars—as is done in the modern Sindhi village—to protect it from the attentions of rats and various insects.

Though as yet it is uncertain how the women dressed, they clearly attended to their personal beauty; for besides the many ornaments unearthed, such as necklaces of beads of gold, silver, copper, glaze, and semiprecious stones, earrings, bracelets, rings, and even nose studs, cosmetic jars are found in their hundreds. All are small, but they are of several different shapes; and they had covers to keep their valued contents clean and safe from the danger of drying up. The men seem to have worn a kind of kilt, not unlike the *dhoti* of the modern Hindu, and a shawl, which was patterned according to the evidence of one of the statues found, just as are the shawls of the Sindhis of to-day in hand-printed colors. This garment was thrown over the left shoulder and drawn round under the right arm like the Roman toga.

Two aspects in particular of the daily lives of these remotely ancient people bring home to us their common humanity with ourselves, their love of children and their weakness for a game of chance. The number and variety of toys found in street and home is remarkable.

Model animals, some of them with heads made to nod by pulling a cord, balls and elephants of pottery that rattle, clay birds that are whistles, toy carts with pottery wheels and drawn by model oxen there are in plenty; and small boys of those days seem to have played with marbles. Numbers of gamesmen are also found, cut in shell or stone, and ivory throwing sticks and dice. The latter have the numbers arranged on different sides from those on modern dice, but no doubt they served their purpose just as well.

Many questions still remain to be answered, and a great deal more spade work must yet be done; but there is no reason to doubt that further finds both at Harappa and Mohenjo-daro and at other sites inhabited by the same people, together with the discoveries continually being made in Iraq and elsewhere, will one day give us valuable clues to the race, the language, and the history of these mysterious people of 5,000 years ago.



RUINS OF THE CITY OF MOHENJO-DARO, IN SIND, BRITISH INDIA, DATING FROM BEFORE 3000 B. C. TO 2500 B. C.
Of the 240 or more acres covered by Mohenjo-Daro, about 13 had been excavated prior to 1927.



1. Horned and tailed figure attacking a tiger



2. Brahmani bull



4. Unicorn



3. Elephant



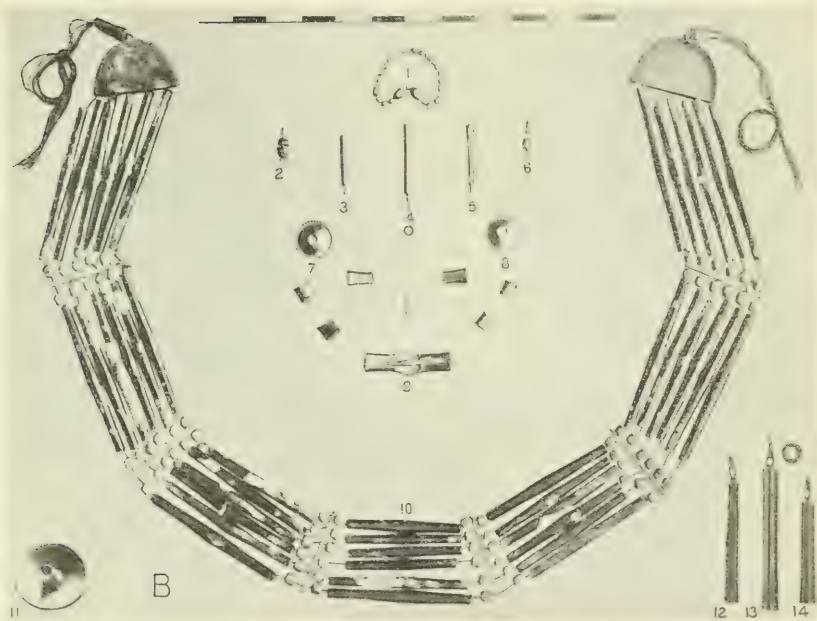
5. A composite mythical beast

SEALS FROM MOHENJO-DARO

These seals are of steatite, white, gray, or black, and mostly square in shape, with a double boss upon the back, through a hole in which a cord was passed so that the seal could be worn at neck or wrist



1. One of the crude toy animals found at Mohenjo-Daro



2. A girdle of fine carnelian beads, each 2 or 3 inches in length, and fragments of faience, from Mohenjo-Daro

SMALL OBJECTS FOUND AT MOHENJO-DARO



1. Head of mother-goddess, pottery



3. Statue head, stone



2. Bronze dancing girl



4. Statue head, stone

FIGURE AND STATUE HEADS FROM MOHENJO-DARO

HISTORICAL CYCLES¹

By O. G. S. CRAWFORD

[With 2 plates]

History has been studied and histories written for more than two millennia. From time to time attempts have been made to discern some pattern or design running through it. But they have usually failed because the data have been inadequate. You can not see the pattern of a carpet when only a minute portion is uncovered, and you can not discern the pattern of history until large portions of it are available for examination. It was not until the nineteenth century that really long vistas were opened up by archeological exploration in the east. Here, in Egypt, Mesopotamia, and Crete, there were found the remains of forgotten civilizations; and Sir Flinders Petrie, one of the pioneers in that work of epoch making in the literal sense, has himself sketched an outline of the pattern he believes he can see emerging. The present essay is an attempt to interpret and explain that pattern.

Only from an altitude of 5 feet or so can the pattern of a carpet be seen; it looks quite different when you are lying on the floor. In just the same way crop markings on an ancient site can only be seen properly from above. To see the sweep of history rather than its details you must stand back and view it from a height of detachment.

History is the time aspect of human affairs—the fourth dimension in which we can not travel. The difficulty may be appreciated by a comparison with geography and the space aspect. Geography is concerned with the surface of the earth, and is therefore essentially a study in three dimensions. Its primary objective is to construct a map of the whole world, and this task, now nearly complete, is performed by millions of measurements of lengths and angles. From this world map gradually emerge certain generalizations, whose very existence may never have been suspected, even by the map makers themselves. The geographer, geologist, and economist generalize upon the basis provided by the surveyor. The geologist can reduce to order the apparently chaotic mountain ranges which cross the

¹ Reprinted, with the omission of one plate, by permission from *Antiquity*, vol. 5, No. 17, March, 1931.

world from the Pyrenees to Patagonia. He can even forecast the probable existence of strata, which, without the map, would forever have remained unknown. (Thus was the Kentish coal field discovered.) These results have all been achieved within the last century or two, and they are made possible by the fact that we can travel in space.

But we can not travel in time. We can not live in ancient Greece or in Ur. It is impossible to compile a chart or chronological table of the past as complete and accurate in its own way as was our world map. The most we can do is to laboriously piece together such fragments as survive, in written records or in the rubbish heaps of buried cities. It must necessarily be a long time before generalizations can be built up on such foundations, before we can see the pattern of history plainly.

There is the added risk of seeing a pattern where none exists. With so many mere scraps of knowledge, the historian of mankind may be tempted to select only those which suit his purpose. But some kind of selective treatment is demanded. If the explanation suggested is the right one, all the facts—both those first selected and the rest—will eventually find their place in the scheme, or at least be found not inconsistent with it; and the theory will come to be accepted. The theory of evolution was formed in this way, and it is, of course, still universally accepted. If the explanation here put forward can be used as the basis of forecasting, it will acquire additional merit.

Complete originality is not claimed for the ideas here suggested. Neither the organic concept of society (the view that it is a living organism) nor the rhythmical or wave theory of civilization is a recent invention. The one has been developed by many philosophers, by Comte, Spencer, Liliensfeld, and Schäffle for instance. The other has been developed by Petrie² and Spengler—and doubtless by others. No one, however, except Spengler, has brought the wave theory of civilization into relation with the organic concept of society and shown that the two are really inseparable. That is what I propose now to do, so far as that is possible within the limits of an article. To elaborate the theory, to clothe the skeleton with flesh, would demand a far greater knowledge of human history and of biology than I can possibly claim. It would be well worth doing. Meanwhile I feel impelled to say something about it, however inadequate, for, if the theory be true, it is obviously of very far-reaching importance.

² Sir Flinders Petrie's *Revolutions of Civilization* (Harper's Library of Living Thought, 3d ed., 1922) was first published in 1911; but the author informs me that the main thesis was worked out by him many years before this date.

Sir Flinders Petrie's views are set forth in a little book of not more than 14,000 words—about twice as long only as this article. Civilization, he maintains, is intermittent; it has its seasons—a spring of preparation, a summer of fulfillment, an autumn of decline, and a winter of death. In each region cycles of civilization have succeeded each other several times; and on each occasion the phases are marked by similar characteristics which may be detected by objective methods of study. The evidence of sculpture is valuable, partly because it is less perishable than most works of art; admittedly, however, it "is only one, and not the most important, of the many subjects that might be compared throughout various ages," but "it is available over so long a period in so many countries" (p. 9). It is therefore used as the main, but not the only criterion in his survey. Others are painting, literature, music, mechanics, and wealth; political development is also brought into the scheme, though only occasionally referred to.

The region regarded as a composite whole is that of Europe and Egypt. The center of gravity shifted within it from Egypt to Greece and thence to Rome and western Europe; but there was throughout the area a series of phases or waves of culture, separated by troughs. During the last 10,000 years or thereabouts he finds evidence of eight phases or great years. The first two are prehistoric; then came five covering the whole dynastic period of Egypt; last of all came the classical and modern (or west European) phases. It is possible to criticize the phases as Sir Flinders Petrie visualizes them, though there are few who have the range of knowledge required for such a task. What matters now is the existence of such phases, which some deny. To this main issue all others are subsidiary. We consider that Sir Flinders Petrie has proved his case quite conclusively. Ever since we first read the book 20 years ago, we have been testing the theory against the background of whatever we have at the time been studying, whether in books or museums or in the world of to-day; and we have found it fit the facts. A theory which works is already half proved.

Each phase passes from archaism through maturity to decline. "The careful working of detail separately, without treating it as part of a whole to be blended together, is the essential mark of archaism" (pp. 21, 22). Note, in passing, that this is a purely objective test, quite free from the bias of taste or prejudice and capable of being applied almost mechanically by an expert. Examples of archaism in art will probably occur to all. Such are the early Greek statues with the "archaic" grin, preceding the period of classical maturity. In the west European phase, archaic beginnings (as at Chartres) blossomed into maturity in the middle of

the thirteenth century (as at Bamberg, Strasburg, and Salisbury). The difference between archaism and maturity is well brought out by comparing the bronze doors of San Zeno at Verona with those panels of mature and almost overripe perfection on the doors of the baptistry at Florence (pls. 1, 2). The same cyclical evolution may be seen in medieval brasses and sepulchral effigies, the period of decline being clearly marked in the stiff and lifeless character of Elizabethan examples.

Similar features are observed in painting and the other arts which, it is claimed, reach their maturity in any given period, not simultaneously but in an orderly succession. Thus sculpture was the first to reach perfection both in the classical and west European phases. Painting reached its zenith in west European art about 1500, literature about 1600, and music about 1800.

There is a tendency for each of these eight phases to last longer than its predecessor, and for the transition or hiatus between each to become greater and (for the people of the time) less uncomfortable.

The last phase before the present, the classical phase, is regarded by Petrie as a single phase. We think it possible however that it was a curve, or wave, with a double peak, or crest, represented by Greece and Rome respectively. It seems too that Rome began where Greece left off, perhaps after some recapitulation of the earlier stages. Is it not possible that the present phase of western civilization also has, though to a less degree, a double peak represented by Europe and America? There are many resemblances between modern America and ancient Rome; and Europe now plays in some respects the rôle of ancient Greece. Europe, like Greece, has been enfeebled by futile internecine strife and competitive armaments; but remains a storehouse of dead art to be ransacked by trans-Atlantic connoisseurs. As M. Merlin has pointed out (*Antiquity*, vol. 4, p. 413) the Romans pillaged Greece in precisely the same manner.

For the rest the reader must consult the book itself, which is too compact and too full of ideas to be adequately summarized. This article assumes as proven the theory there set forth, and attempts to correlate it with a yet more inclusive generalization. Some day, perhaps, we may develop it in full.

A few words, however, must be said about its causes which Sir Flinders Petrie suggests as responsible for the existence of phases. Whether they wholly explain the cyclical development of culture may perhaps be questioned. It is probable, however, that they are at least contributory causes, as he himself says. He points out that the phase or great year is heralded by invasion. Historically these invasions have generally been from colder into warmer lands, from

regions where life is hard into those where it is easier. Inured to striving in their homeland, the invaders have developed by natural selection into a race of hardy folk; and the impetus of their more energetic mode of life carries them forward, in the better land of their adoption, to greater and higher achievements than the natives. They "thrive vastly" there, "until their tone is let down to their conditions" (p. 125). There are, moreover, many new problems of adjustment to be solved. When this is achieved and a régime of living established, complete freedom of expression is soon gained and "strife being ended, decay sets in shortly after." The accumulation of capital contributes to the same result, by lessening the need of effort. "The maximum of wealth must inevitably lead to the downfall" (p. 126).

Changes of climate may be another contributory cause, and periods of desiccation do actually coincide with periods of migration, but they do not (Petrie thinks) account for the regularity of the phase. This he attributes to the lapse of time required to effect a complete fusion of different racial stocks, which he calculates should take from six to eight centuries, and the explanation, wherever it can be tested by the facts of history, seems adequate. "The complete crossing of two races produces the maximum of ability, and * * * from that point repeated generations diminish the ability * * *. But probably each of the other causes before noted may bear a part" (p. 124). He concludes with the suggestion that "eugenics will, in some future civilization, carefully segregate fine races and prohibit continual mixture, until they have a distinct type, which will start a new civilization when transplanted. The future progress of mankind may depend as much on isolation to establish a type as on fusion of types when established" (p. 131).

As a corollary of this we would add that the longer a culture remains isolated, developing along its own lines, the more specialized it becomes and the less easy it is to cross it with another. It gradually becomes a different species. It is a biological fact that the mating of individuals of different species is infertile. Too great contrasts produce sterility. It seems also to be a rule of history that when a higher (or more advanced) culture invades and conquers a lower it exterminates it and often the people too. Thus the Roman invasion killed late Celtic art in Britain, and western civilization has proved fatal to many primitive races. The invasion of one barbarism by another is also infertile and might perhaps be compared with the marriage of children. It seems as if the relative age of mating cultures has got to be exactly right, as well as the degree of their affinity.

The new phase is conceived when the invader cells swarm in from without. The social body gradually takes shape; the structural lines form and become more and more complex. With maturity comes full self-consciousness. With the approach of age the culture gradually loses energy until at last it dies, generally to be reborn in the same manner. These processes obey the laws of growth because they are life processes. They can not be forced. Violent attempts to do so generally fail (though sometimes they may be as necessary as a surgical operation). The way to stimulate growth is by means of educational propaganda.

What emerges from all this, is, we think, a generalization of wide and far-reaching importance, namely, that each phase of civilization has a life of its own and may be regarded as if it were a species composed of living creatures. The phase as a whole corresponds to the life of the species as a whole; the units composing the phase at any given moment of history (the human beings) correspond to the individuals composing the species. Both come into existence and pass through maturity to decline and extinction, to be replaced as a rule by another phase or species issuing from it. The evolution of culture is exactly parallel to the evolution of organic life as a whole.

The idea is not of course new; but it has never, we think, been effectively grafted on to the wave theory of civilization. One of its most recent advocates, Sir Arthur Keith, goes so far as to say:³ "The resemblance between the body physiological and the body politic is more than an analogy; it is a reality."

The cultural community is the unit, and, to conserve the analogy, it is a multicellular organism. But, in point of fact, multicellular organisms have evolved from a single cell, and if the analogy is a just one, we should find that communities have done so too. History tells us that they do. The unit of the multicellular organism is a single cell; the unit of the community is a single human being.⁴ We may take *Homo Sapiens* when he first appears as representing this unit, before its incorporation into the first community, represented, in a slightly advanced stage perhaps, by the city states of Sumer (Ur, Kish, and so forth). The transition may have been relatively abrupt, for we now know that, up to about 5000 or 4000 B. C., the caves of Kurdistan were still inhabited by primitive stone-age individuals, as they had been for countless ages before. The latest relics found in the top layers of these caves correspond exactly with the

³ Concerning Man's Origin (Putnam, 1928), quoted in a most suggestive article on cancer in the *British Medical Journal* (October 5, 1929, p. 607), by W. Sampson Handley, M. S., F. R. C. S.

⁴ Barth regarded the family rather than the individual as the unit.

earliest found in Sumer and Assyria.⁵ Clearly therefore at some date round about 5000 B. C. the solitary free-roving human cell was integrated into the multicellular organism of a community.⁶ The same change occurred elsewhere, probably about the same time. The predynastic Egyptians succeeded the neolithic desert rovers of the Sahara, and may well have been directly descended from them. The neolithic Cretans became the citizens of Cnossos.

Together with this integration, and as a necessary accompaniment of it, there developed specialization of function. The hunter is a law unto himself, self-determined and independent, just like the free-swimming cell. The citizen of a civilized community has already sacrificed much of his independence in exchange for more leisure and an easier mode of existence. Division of labor has arrived, and with it all the implications of the social contract.

The course of biological evolution is very similar. From the single cell there developed, some eleven hundred million years ago,

organisms composed of many cells living together in a communal life like that of a small village or a great city. The cells are now specialized into groups, and each kind of cell follows a trade or profession, exerting for the community its special skill, receiving from the community in exchange food, warmth, and protection. To carry out the scheme and to insure that each cell receives its due share of food, and of such cell products as it no longer makes for itself, elaborate systems of conduits—the circulatory, lymphatic, and glandular systems—have been evolved; and equally elaborate machinery, comparable with the telegraphs, telephones, and newspaper and business offices of the city, brings information of the outer world, and controls the activities of the cell community.⁷

Civilization advances by the integration of its cells into ever larger and larger organizations—from the family to the tribe, city, and nation, and from nation to empire, confederacy, and league. The process, as we have seen, is not continuous but spasmodic. The integrated multicellular community is an organism with a life cycle of its own. The cycle ends with the break-up or death of the organism. The tribe is dispersed; the city is destroyed; the nation decays, shrivels up, and disappears. But a new one generally⁸ rises from the ashes of the old. The constituent cells, the individual human beings, live

⁵ In caves near Sulaimanya in southern Kurdistan, Miss Garrod found Mousterian (old paleolithic) flint implements in the lower layers, overlaid by a later paleolithic layer and finally by a top neolithic layer containing painted pottery of the antediluvian Sumerian type. See Bull. Amer. School Prehist. Research (G. G. MacCurdy, director), No. 6, pp. 8-43, March, 1930.

⁶ We may, of course, regard whatever lay between the solitary hunter and the village or city state as transitional and as corresponding perhaps to the early cell aggregations of biology—such as flagellate colonies, sponges, and polyps.

⁷ Handley in British Medical Journal (op. cit. supra).

⁸ But not always; some of the American civilizations for instance have vanished utterly and have not been replaced by any other.

on; and though not individually immortal, like body cells, they are so in bulk, and in effect.

It is this multicellular social organism⁹—or rather the species to which it belongs—that, during its phase of existence, passes through those stages which Sir Flinders Petrie has described. We may speak of this unit as a culture, a civilization, a community, or (metaphorically) as an organism. These, however, are abstractions. What we are dealing with in reality is a unit or individual in four dimensions. The community—such as a city state, for instance—has a geographical extension in three dimensions and a temporal one in the fourth. Its full content is, let us say, 200 square miles \times 500 years.¹⁰ This is perfectly plain when we are dealing with a multicellular organism like a human being, whose biography can be written. Civilization, when it first appears, represents life organizing itself again *de novo* at a higher level of consciousness, taking as its unit or brick an intelligent human being instead of an unintelligent cell. Obviously therefore our inquiry into the origin and nature of a civilized community must begin with an investigation of the origin and nature of this human being; just as the study of biology begins with the problem of the origin of the living cell from which all living things are descended. The biological problem is still unsolved, but there seems to be a fundamental difference—can it be merely one of organization?—between living and dead matter. The birth of life marks the beginning of a new chapter, though we can not find the page in the book of nature.

So, too, there is an uncertainty about the precise moment when *Homo Sapiens* emerged from *Homo Insipiens*, but everyone recognizes the difference between, say, the most primitive savage and his lemurian ancestor. Another new chapter has been begun. It may be suggested that the essential change is from instinctive to intelligent reaction, or, stated in other terms, from passive adaptation to environment to active control of it. (This does not of course imply that instinct and adaptation cease to function; we know that they do; it is rather comparable with the fact that living matter retains many of the properties of dead matter, along with the new ones added.) Man as such comes first upon the stage when he becomes a tool-making animal; that marks the beginning of chapter 2, chapter 1 being the birth of life.

⁹ In the analogy we compare the life history of a human community with the life history of a species. But we compare the organization of that community to the organization (structure, function, etc.) of the individual multicellular organism. The human community recapitulates, as we shall see below, the life history, not of the individual organism but of the species. But since the organism itself, as the species develops, recapitulates its own evolution, there is a general resemblance between the life history of both organism and community.

¹⁰ There is also, of course, a certain thickness, but for our present purpose this may be ignored.

For countless ages man remained a solitary tool-using hunter. He improved his tools and evolved physically as an animal, from the stage represented by the Piltdown skull to that of the later cave dwellers where, physically, he still remains.¹¹ Then, somewhere about 5000 B. C., when the Ice Age was practically over, he began a new chapter by discovering agriculture and the domestication of animals, and by ceasing to be a wanderer. That was the second epoch-making discovery of human history, for it made sedentary life in communities possible. Some freedom of movement was temporarily sacrificed for the innumerable compensations received in exchange. We are still living in this chapter.

The essence of this new integration of human society is surely that it is, to a far greater extent than the first, a self-conscious unit. The degree of self-consciousness in a community may be relatively greater or smaller, but it is invariably present in some measure. By some it is nowadays called patriotism, by others group consciousness. Patriotism in the last resort is merely the mutual offensive action and reaction of communities; it could not exist without an inherent potentiality of conflict. This new self-conscious unit has come into existence through the amalgamation of hitherto separate individuals. It is a new manifestation. It stands in the same relation to the individuals which compose it as does the whole body of an animal to the cells of its body. It has in fact evolved in much the same way. Why has it done so? Surely because, being a form of life, it obeys the laws of development of all living things and recapitulates. It is even possible to be more precise. If this is recapitulation, it should be of much shorter duration than that which is recapitulated. We do not, unfortunately, know how many years it took to evolve the first multicellular organism from the first cell, but we can not err in reckoning it in hundreds of millions of years.¹² From the invention of tools to the first city state can not have been more than a few hundreds of thousands of years at the outside, for man himself is not much older.

It next becomes necessary to determine, if we can, to what biological stage or stages belong the civilized communities of historic times. To do so we must examine the characteristics of a civilized community.

It is primarily a self-conscious unit acting as a single whole. This implies a single directing brain or seat of consciousness which can compel such action or rely upon its performance. "The simplest rudimentary conception of political action is this, that one man

¹¹ For an elaboration of this argument, see my *Man and His Past* (Oxford, 1921), especially the first two chapters.

¹² See *The Science of Life*, by H. G. Wells, J. S. Huxley, and G. P. Wells, vol. 1, p. 207 (table of geological formations with approximate relative lengths and duration in years).

imposes a command upon another.”¹³ (There may, of course, be the complications of decentralized control, but they do not affect the main proposition.) A civilized community has therefore definitely got beyond the stage of mere cell aggregations. Perhaps the city state of Sumeria corresponds to a trilobite. It is in Sumer that we find the earliest clear manifestation of group consciousness, represented, precisely as it should be, by the deification of the city itself.

At Fara, the most primitive Sumerian site that has yet (in 1916) been examined, we find the god Shuruppak giving his own name to the city around his shrine, and Ningirsu of Lagash dominates and directs his people from the first. Other city gods . . . are already in existence. . . . The authority of each god did not extend beyond the limits of his own people's territory. Each city was content to do battle on his behalf, and the defeat of one was synonymous with the downfall of the other.¹⁴

Here we have, at the very dawn of history, precisely what according to our theory we should expect to find—the self-consciousness of the new individual, the group, expressed in terms of religion, and its patriotism in terms of conflict.

The character of the community is best seen in action; and in primitive civilizations external action is generally synonymous with warfare. Primitive tribal warfare, like the still earlier encounters of individual hunters, is the blind instinctive clash of conflicting interests, acting usually under the stimulus of hunger or sex. The reaction, too, is direct and immediate. The warfare of city states probably proceeded from similar causes; but it was less instinctive and more intelligently controlled. The warfare of European nations, or of groups of nations, probably represents the highest achievement of concerted group action yet reached by the human race. It is therefore necessary to devote a few lines to it, in order to see more clearly what biological stage we have to-day reached in our recapitulation.

The organization of a modern army in the field is a very beautiful thing. Such an army is a most delicately adjusted living organism, whose morale—rightly prized very highly—is its soul. It consists also of brain and body; the commander in chief is the brain; the soldiers in the fighting line are the body, or rather part of it. Impressions from the outer world (where the enemy resides) reach the brain through the organs of sense. In an army the flash spotters and airplane observers are the eyes, the sound rangers, the ears, the observers in the front line are like antennae or fingers, the army service corps is the stomach and legs, the corps of signalers the nerves. Signals reach the intelligence department which, like the neopallium, coordinates the impressions received, and, itself a part of the brain,

¹³ Seeley, Sir J. R., *Introduction to Political Science*, p. 89, London, 1896.

¹⁴ King, L. W., *A History of Sumer and Akkad*, pp. 84, 85, London, 1916.

transmits them to that other part of itself which directs action, the department of operations. Thus informed, the will, the commander in chief, issues orders which travel along a hundred nerves, each to its destination, and at zero point the army moves forward.

In its normal everyday life a community might act in a similar way, if there should be a centralized control and a well-developed group consciousness. Some nations and city states have thus acted at their maturity, when the civic body is still young and healthy and its reactions quick and senses keen. It can only do so even then when it has a sovereign capable of directing its actions, and history shows that this combination does not often occur.

It is plain that some modern nations have reached, in their recapitulation, an already advanced stage. It would need a biologist's knowledge to give precision, however, to the analogy at this point, and this unfortunately we do not possess. Perhaps modern European states are passing through the stage of vertebrate or even mammalian life.¹⁵ Perhaps, however, they are merely having a reptilian nightmare on the road to mutual extermination, and the torch may be picked up later on by some now obscure racial group on the confines of western civilization. In favor of the first suggestion is the fact that modern states have a brain; in favor of the second that it is a small and poor one and only used in extremities. Whichever equation we adopt, this advance from multicell to vertebrate (whether reptile or mammal) is of far shorter duration than that from a single cell to a many-celled organism; and the corresponding advance from city state to modern nation is proportionately shorter, as it should be. May we not conclude then, that there is a good case for regarding social evolution as a recapitulation of organic evolution?

Before passing on to the next point it should be noted that in social as in biological evolution there is a main line or stem, with branches. Some organisms have branched off and have either become extinct or have remained down to the present day in their primitive state, living on side by side with their more advanced cousins. Some advance to a point and remain there, or go backwards. These branchings off occur at every stage. Paleolithic hunters are now extinct,¹⁶ but neolithic collectors survive in the Australian aborigines, and elsewhere; just as primitive forms of life abound in every pond.

It has already been seen that, according to our theory, the phase or life history (in Petrie's sense) of a society is equivalent to a species,

¹⁵ Sir Arthur Keith, however (1924, p. 9) considers that "the highest stage which has been yet reached by man in the evolution of human societies has hardly passed beyond Nature's lowest stage—that represented by sponges." We have no room here to argue the point, which moreover is not relevant to our main thesis.

¹⁶ Unless the Esquimaux be taken to represent them; but the Esquimaux are not solitary hunters.

whose evolution it recapitulates; and that both evolve in the same kind of way, from simple to complex. In both, too, the most important fresh starts originate not from the most advanced members but from those which have not sacrificed their primitive plasticity to premature and excessive specialization. It was the Nordic barbarians on the fringe of the Roman world who initiated the modern phase; they were in touch with Roman civilization but not part of it. The classical phase was started by barbarians from central Europe, in touch with the *Ægean* world but not of it. The last great advance in evolution was made by an insignificant little creature whose very existence was probably unknown to the reptilian overlords it eventually superseded.¹⁷

Looking at the process as a whole it would seem that life evolves in a spiral. It begins with a single cell. After countless ages of complex development an organism is evolved which becomes in its turn the unit of another cycle. We are back where we started, but on a higher plane. The human being becomes the unit of organized society, and this, we must suppose, will evolve till it, too, in turn becomes the single complex unit or individual of yet another cycle. Clearly this process foreshadows the ultimate achievement of a single world state, in which the whole human race shall be organized as a single social organism. This need not necessarily imply that every existing race and society will be at once incorporated in the world state. When the last new start was made with the formation of human society, other forms of life, represented by other species of animals and plants, were not all caught up into the new organism, but only such as were of use to it and which could find a place in it, and those but gradually. Domestic animals and, later, plants—dogs, cats, horses, cattle, sheep, goats, pigs: Corn, palms, olives, vines—were adopted and are still an essential element in human society; they therefore survive. Those animals which do not, or which are definitely antagonistic to it, having refused to become incorporated, tend to become extinct. There were many more species in paleolithic and even in neolithic times than there are to-day, and the extinction of the larger fauna is now proceeding with great rapidity.

We may therefore expect that those human societies and races which can not be assimilated by the world state will eventually die out.

This world state is also foreshadowed by the international character of science. The growth of the conception of a pool of world knowledge would be interesting to trace. There is now coming into

¹⁷ Smith, Prof. G. Elliot, presidential address, section H, British Assoc. Adv. Sci. (Dundee). Report, pp. 575-598, 1912.

existence a body of knowledge, collected by workers in this universal intelligence department, for the use of future directors of operations. Unfortunately (as we think) thought has outstripped the means of action. The existing forms of political organization, though already out of date, make use of this knowledge not for the general good but for lower and more immediate ends, including that of mutual extermination. Still more unfortunately they are aided and abetted in this task by men of science themselves who should know better. Perhaps, however, the new phase can only arise from the chaos of the old one when it crashes; so that the sooner this happens, the sooner the next phase will begin.

If this new cycle of evolution is to return spirally like the rest to a point immediately above its starting point, the world state will be equivalent to the human being in organic evolution; just as the present states were equivalent to some earlier animal. This must follow logically from the recapitulatory process now in progress, and may even be forecasted as its inevitable goal. The work of integration and reintegration of "individuals" persists and follows recognizable "laws." What the cell is to the human body, the human body is to the world state. What is to be the next integration, in which the world state will be merely the single unit, cell, or, as Prof. Julian Huxley would call it, "third grade individual"? Is there going to be another? If there is it can hardly be of this world alone, since the whole world will be its body.

Can we extend the analogy backwards and detect the unit which is to the cell what the cell is to the human body?

We can at least see that, if the analogy here sketched is sound, the evolution of life proceeds upon an orderly plan, intelligible and possibly predictable. We see that the very large is explicable in terms of the very small, just as in physics. In the probability waves which determine the emergence of certain features of civilized life, we catch an elusive, perhaps delusive, yet fascinating glimpse of behavior which seems to resemble the behavior of the constituent ultimate elements of matter. Sometimes we think we can see some meaning in the dance of shadows upon the wall of the cave; and then we lose it again. Was it really there? Or was it only our own shadows that we saw?

NOTE I

No attempt has been made in the above article either to anticipate objections to the theory propounded in it, or to deal with criticisms which have been made about the cyclical view of history. It seemed better to set down the writer's own ideas as clearly and as briefly as possible. Any other course would confuse the issue and expand the

account to an impossible size. For similar reasons little reference has been made to previous writers, though acknowledgments have been made whenever the parentage of an idea or a statement was known. In addition to the books or articles already referred to the following may be quoted:

Social Adaptation: A Study in the Development of the Doctrine of Adaptation as a Theory of Social Progress, by Lucius Moody Bristol. Harvard Economic Studies, vol. 14. Harvard University Press [Milford, London], 1915.

Warfare in the Human Body: Essays on Method, Malignity, Repair, and Allied Subjects, by Morley Roberts. Eveleigh Nash, London [1920].

Does Man's Body Represent a Commonwealth? by Sir Arthur Keith. The R. P. A. Annual, 1924, pp. 2-12.

Concerning Man's Origin, by Prof. Sir Arthur Keith. Watts, London, 1927.

The Theory of Historical Cycles, by R. G. Collingwood. I. Oswald Spengler. *Antiquity*, vol. 1, pp. 311-325, 1927. II. *Cycles and Progress*, *ibid.*, pp. 435-446.

Note of criticism on the above, by Sir Flinders Petrie, published in *Antiquity*, 1928, vol. 2, pp. 207-208.

The Ascent of Humanity: An Essay on the Evolution of Civilization, by Gerald Heard. Jonathan Cape, London, 1929. Reviewed in *Antiquity*, 1930, vol. 4, pp. 5-11.

The above list does not claim to be in any sense a bibliography or even a complete list of "books and articles consulted." Some of these, and among them some of the most important, have been quoted already in the footnotes. Some account of the principal philosophers who have dealt with the subject will be found in the books quoted, particularly in the first mentioned (Mr. Bristol's).

NOTE II

The early stages of integration are naturally the most difficult to observe, partly because in them it is very difficult to say whether the unit is the evolving group or the individual forming part of it; and partly because historically the hypothetical nomadic precursors have vanished leaving but the scantiest traces of their existence. Their very mode of life insures this. Precisely the same difficulty is encountered in biology.

Which are the individuals of the colonial polyp *Obelia*—the polyps at the end of the branches or the colony as a whole? If separateness be the criterion the colony is the individual; but what then of the medusae, for a time part of the colony, then budded off to lead an independent existence? A single worker ant is separate and distinct enough; but it is not independent, and has no more biological meaning apart from the ant community than has a human finger amputated from the body.

The writer decides that

An individual is not a stable thing in itself, but rather a history, a series of events tied together and unified in a particular way.

In other words, individuality can only exist in four dimensions.

It is a method of acting and becoming; it is never identical with itself for two consecutive moments of its career. When we take it at any given moment and examine it, it possesses * * * a certain degree of unity in its construction, a unity in space. When we look at it as a history, we find that it has a certain unity in time. The different events of its history cooperate to insure its own continuance or the continuance of new systems like itself.¹⁵

This description applies admirably to any one of Petrie's phases, or to any of its component units. The thread of unity here is provided by tradition, the outcome of speech and writing. (The writer's debt to this article of Professor Huxley's will be obvious, and he wishes gratefully to acknowledge it.)

NOTE III

[Added January, 1933]

In correcting the proofs of my 1931 article I have made only one alteration of meaning, and that a minor verbal one. It seemed better to leave it exactly as it stands, for it exactly expressed my views at the time it was written. I would not express myself in the same way if I were to write an account of *Historical Cycles* to-day, for I should write from the point of view of a Marxist. I believe that one of the most immediate tasks for students of the history of material human culture is to discover the material cause of historical cycles; for their existence can not be called in question. Before this can be done, however, a world history must be "written from the standpoint of dialectical materialism, which alone can make the dynamics of history comprehensible" (John Strachey in *The Coming Struggle for Power*, p. 189, Gollancz, 1932).

¹⁵ Huxley, Julian, *What is Individuality?* *The Realist*, vol. 1, No. 1, pp. 109-121, April, 1929.



Photograph by Anderson, Rome

BRONZE DOOR OF CHURCH OF SAN ZENO, VERONA (1139), AN EXAMPLE OF
ARCHAIC DESIGN



Photograph by Alinari

PANEL OF BRONZE DOOR AT FLORENCE, COMPLETED 1452, AN EXAMPLE OF MATURE SCULPTURE

THE "GREAT WALL OF PERU" AND OTHER AERIAL PHOTOGRAPHIC STUDIES BY THE SHIPPEE-JOHNSON PERUVIAN EXPEDITION ¹

By ROBERT SHIPPEE

[With 10 plates]

The appearance of "Peru from the Air," ² was followed by many requests for a continuation of the studies contained therein. In no field have the rewards of aerial survey been greater than in archeology, and the demand has been increasing for "more maps and more air photographs," as Crawford has phrased it. To meet this demand and the demands of geography were two of the chief objectives of the Shippee-Johnson Peruvian expedition of 1931. The expedition planned to record the most important ancient sites of Peru by oblique and vertical photographs and mosaic maps. We had little expectation of making really new discoveries in a country where exploration has already revealed so much. We were quite unprepared for the "Great Wall," as it has been popularly termed.

THE GREAT WALL

While we were still operating from the base that we had established at Trujillo for the mapping of the well-known ruins of Chan-Chan, we made a flight with the photographic plane inland as far as the Marañon River and, on the return, circled southward around Mount Huascaran and then followed the valley of the Santa River to the coast. Our course was over the edge of the foothills bordering the narrow upper valley of the river on the north. Johnson, co-leader and photographer of the expedition, watching for photographic subjects, noticed what appeared to be a wall flowing up and down over the ridges beneath the plane, wondered for a moment as to the purpose of such a structure, decided that it was worth record-

¹ Copyright, 1932, by the American Geographical Society of New York. Reprinted by permission from the *Geographical Review*, vol. 22, No. 1, January, 1932. The 29 illustrations which originally accompanied this article have here been reduced to 20, appearing as 10 plates.

² Johnson, George R., and Platt, Raye R., *Peru from the Air*, Amer. Geogr. Soc. Special Publ. No. 12, New York, 1930.

ing, and made a number of photographs of it. We hoped to be able to return later to make a more complete record of the wall but were not certain that we should have time to do so. The photographs, printed a few weeks later in our Lima laboratory, led to so much discussion, however, that just before our departure we arranged to

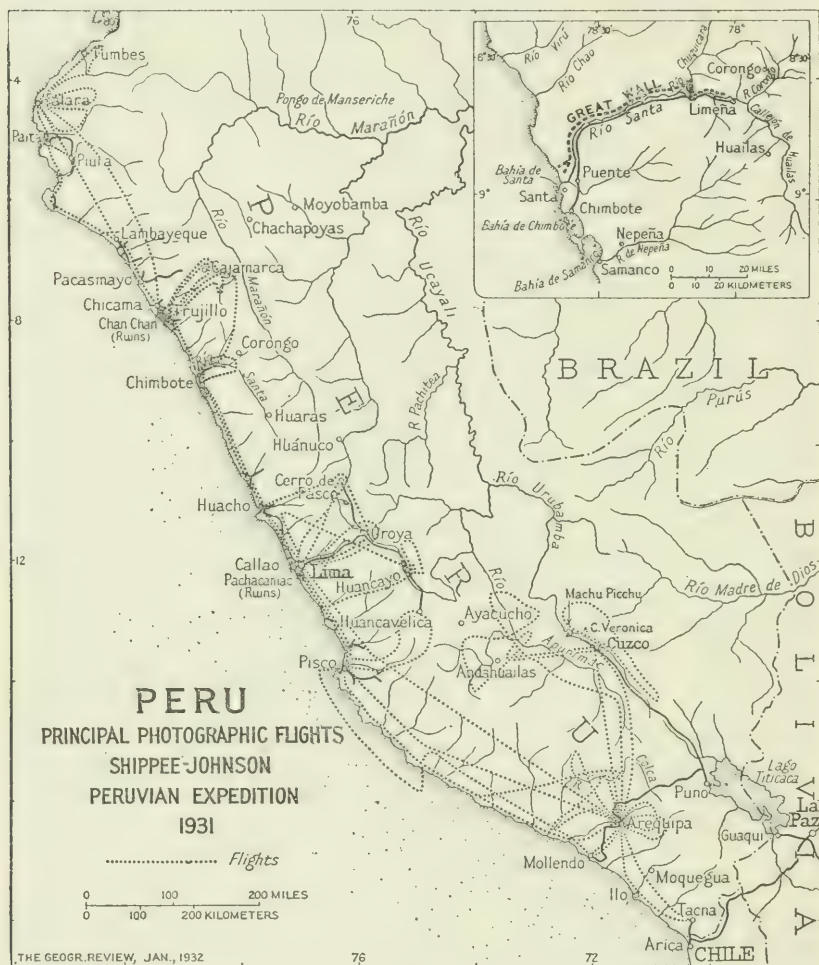


FIGURE 1

make a special trip to relocate and examine the wall from both the air and the ground.

Johnson and I, with our Peruvian observer, Captain Ceballos, flew to Chimbote in the photographic ship and established a temporary base there. Chimbote lies on one of the largest bays of the Peruvian coast, a few miles south of the Santa Valley, of which it is now the principal port. The little town in the lee of three tall, barren sand

hills can boast of two things only—a natural harbor that would make the most ideal naval, aviation, or submarine base imaginable and a level, hard landing field that is used by the Peruvian commercial air lines.

The natives of Chimbote assured us that they knew about the wall, that they had heard of it from their ancestors, and that it was pre-Incaic. They could tell nothing, however, of its purpose or its history and, indeed, gave little real evidence that they had ever even heard of it.

From Chimbote the flight to the mouth of the Santa River was a matter of a few minutes only. Turning inland from there we picked up the wall about 5 or 6 miles from the coast at the ruins of a small village. At that end the wall divides into two sections for a short distance as shown in Plate 1, Figure 1. It may have once extended to the shore line; but, if it did, it has been broken down, and the stones have either been removed for other building purposes or covered by the drifting sand.

From the ruined village, itself all but lost under the sand, the wall leads away up the north side of the river, first across the level, sandy plain of the river delta and then, as the valley narrows, over the edge of the foothills bordering the valley. As the foothill ridges become sharper and steeper, the wall rises and dips and in places is turned slightly from its generally straight course. Its distance from the river is in general about a mile and a half, although in one place at least it dips down close to the edge of the river bed. In places it blends so well with the background as to be almost indistinguishable.

It was impossible to make an accurate check on the distance we followed the wall, for the air was so unusually rough that, as we approached the Andes, we had to circle and climb for more and more altitude; but we followed it for at least 40 miles and possibly more. Then we lost it. We had already passed over several short breaks, but this time we failed to pick it up again. The light, which was poor when we started—for the flight was made in August, a winter month, when the coastal valleys are nearly always overcast and often filled solid with fog—was getting rapidly worse; so we headed back for Chimbote, taking only a few minutes out to get more close-ups of the forts on both sides of the wall.

It so happened that none of our first photographs showed any of these forts. But, on this second flight we noticed at irregular intervals on both sides of the wall, but at short distances from it, a series of small forts—some circular and some rectangular—most of which were more or less inset in the top of small hills so as to be quite invisible from the valley floor. Those on the south side, and they were the larger, were located in the hills on the south side of the Santa

River opposite the wall. We believe that we located and photographed all of these forts—a total of 14. The largest one appeared to be about 300 feet by 200 feet, with walls about 15 feet high and perhaps 5 feet thick, and was of piled-stone construction. A few of the others were of the same construction, but most of them appeared to be of adobe.

At Chimbote we at once began preparation for a trip to the wall overland. From a rough sketch made while in the air we figured that we could reach at least the western end of the wall by automobile. There is a bridge over the Santa near its mouth, and, once on the other side, it would be simply a question of how far the car could plow through the sand. The next morning we loaded our equipment into an old Ford and started off on a trip that was to take five hours of bumping over crude roads, slithering down muddy cow paths, and pushing through deep sand. Steering our course by a method of "dead reckoning" especially devised for the occasion, we at last reached the sand-covered ruins of the little village at the end of the wall. It was just by chance that we did not miss them entirely. From the air we had been able to make out the plan of the streets and the walls of the separate houses. From the ground we saw nothing but a few sand-covered ridges.

Just beyond these ridges, which were crumbled adobe walls buried beneath centuries of drifted sand, we saw the wall stretching away to the horizon. We followed along it for several miles. Then the valley began to narrow and the cross ridges to dip more sharply down to it. The Ford could go no farther. We struggled on afoot for another mile, lugging the cameras and stopping at intervals for still and motion pictures showing construction details and the character of the terrain on which the wall stands.

The wall, as far as we followed it, now averages about 7 feet in height. It is built of broken rocks set together with adobe cement, and, where it has not been greatly disturbed, its outer surface is so well chinked with small rocks that it would be practically impossible to scale it without ladders. In occasional places, as seen from the air, the wall must still be 20 or 30 feet high where it crosses gullies. We found it impossible to make anything like accurate measurements. The rocks that have slipped from the top with the beating of the winds and the occasional rains spread away for a considerable distance on either side of the wall and aid the drifted sand in obscuring its base. We estimated that, in its original state, it was about 12 or 15 feet thick at the base and was built to taper upward to an average height of 12 or 15 feet.

ORIGIN OF THE WALL

We were unable to come to any conclusion concerning the origin of the wall. As Dr. A. L. Kroeber remarks, that will require careful examination by an archeologist familiar with different types of construction and able to interpret potsherds or other fragments that may be found in association with the wall. If we had had time to carry our ground explorations farther and to investigate the forts, we might have found more definite indications as to its history; but we had already spent eight and a half months in Peru instead of the five months originally planned.

Further exploration to determine how far the wall extends into the Andes would be especially worth while. We estimate that when we finally lost sight of the wall we were in the neighborhood of Corongo. Wiener³ mentions strongly fortified hills in the Corongo region. We have, therefore, the possibility of a defensive wall joining the fortifications of the Corongo region with those at the mouth of the Santa River.

Clearly the wall with its double line of forts was erected as a defensive barrier. If it is true that the fortified hilltops at Paramonga, some 50 miles farther south, mark the southern limits of the domain of the Great Chimú, there are many guesses that can be made as to the origin and purpose of the wall. It may be an intertribal defense that antedates the consolidation of the Chimú kingdom. Or it may be a secondary line of defense erected by the Chimú against the Inca invader. If the latter is the case it may explain why, as tradition says, the Inca abandoned his invasions of the Chimú kingdom from the south along the coast and finally conquered it by advancing his armies through the Andes and laying direct siege to Chan-Chan, the Chimú capital.

The suggestion has been advanced by Dr. R. L. Olson, of the University of California, that the wall may represent one of a series of defense structures built by the Chimú as they extended their territory to the north and south.⁴ While engaged in field work in this part of Peru two years ago Doctor Olson noted a number of walls in the Chao Valley, about 20 miles north of the Santa Valley, mostly fragmentary and running for short distances only. He describes a larger wall cutting across the pampa between Trujillo and Chicama that was built presumably for the defense of Chan-Chan.

³ Charles Wiener, *Pérou et Bolivie*, Paris, p. 177, 1880.

⁴ From a preliminary statement sent to the American Geographical Society at the instance of Dr. A. L. Kroeber.

Prof. Marshall H. Saville suggests that the wall may have been erected by the Chimú or pre-Chimú occupants of the Santa Valley to prevent the neighboring tribes on the north, or possible invaders from the north, from gaining access to the river where, by damming or otherwise diverting the stream, they could cut off the water supply from the great aqueducts, still largely in fairly good repair, that irrigated the densely peopled Santa delta. In connection with this suggestion may be cited Montesinos's account that the Inca finally conquered the Great Chimú by cutting off his water supply.⁵ It may have been the supply to the Santa Valley that was cut off by the Inca, since Montesinos does not state which valley it was in which the Chimú finally capitulated, while Garcilasso de la Vega⁶ says that it was the Santa Valley, although he makes no mention of the cutting off of the water supply.

Dr. Julio C. Tello, director of the archeological museum of the University of San Marcos and a leading authority on the Inca and pre-Inca civilizations, states in reply to a letter addressed to him by the American Geographical Society that not only had he never heard of the wall until it was reported by the Shippee-Johnson expedition but that he has been unable to find anyone among the owners of the large haciendas in the Santa Valley who knows anything of it. Doctor Tello reports that he has discovered several walls similar to the Great Wall of the Santa Valley in valleys south of Lima, although none of them is more than a few kilometers in length. He also mentions the wall between Trujillo and Chicama described by Doctor Olson, but offers no suggestions as to the possible purpose of this or others of what he describes as the "mysterious walls of Peru."

It is still hard for us to believe that we have actually made a new discovery of such evident importance in a region whose ruins have been for more than 75 years the subject of frequent and careful explorations by a long list of noted archeologists, many of whom have made their reputations there. From the air, the wall and its forts are so striking a feature of the landscape that it is difficult to understand how they could have so long escaped notice from the ground. That this is the case seems less astonishing, however, when one considers that, even though the wall were noticed at its western end where it crosses the delta of the Santa River, it would appear only as one more wall in a region filled not only with the ruins of

⁵ Montesinos, Fernando, *Memorias antiguas historiales del Peru*, translated and edited by Philip Ainsworth Means, Hakluyt Soc. Publs., ser. 2, vol. 48, p. 48, London, 1920.

⁶ De la Vega, Garcilasso, *First Part of the Royal Commentaries of the Yncas*, translated and edited by Clements R. Markham, Hakluyt Soc. Publs., ser. 1, No. 45 (2 vols.), vol. 2, pp. 196-201, London, 1871.

elaborate fortifications—fortified hills and defensive walls of various sorts—but also with the remains of cities, towns, and extensive irrigation works. Only when one looks down upon the wall from the air and thus is able to see long sections of it can one realize that it is a feature quite distinct from the short sections of wall characteristic of the Santa delta. This broad view presented to observer and camera is what makes the airplane so important an instrument in modern exploration. The aerial observer is afforded, and the aerial camera records frequently in a single exposure, a synthesis of details whose relationships might otherwise never be discovered.

SURVEYS OF CHAN-CHAN AND PACHACAMAC

The base at Trujillo from which we made our first flight over the Great Wall had been established for the purpose of making a mosaic map of the ruins of Chan-Chan, the capital of the kingdom of the Great Chimú whom the Incas conquered shortly before the Spanish conquest. The ruins have recently been described by Maj. Otto Holstein in an article in the *Geographical Review*. He particularly called attention to the disastrous effect of the rains of 1925 and urged that systematic study of the site be made without delay.⁷ Johnson had had it in mind for some time to make an accurate record of these ruins, based on a good triangulation, before another rainy year like that of 1925 had completed their destruction.

The ruins occupy an area of about 11 square miles. From a base line of 3,600 feet two of us with a detail of soldiers lent us by the Trujillo garrison triangulated the entire area and laid white line markers. It was difficult to work with any speed and still obtain the degree of accuracy for which we were striving, for the high adobe walls and the rounded bulks of the huacas so interfered with the sights that we had to choose all points with great care. Three and a half days were required for the completion of the triangulation.

On the other hand, in 40 minutes from the time the plane took off for the aerial survey the wheels again touched ground with the survey completed. Furthermore, when we came to the assembling of the mosaic, we found that the only corrections our photographs needed were those required to offset the slight variations in the altitude of the plane while the photographs were being made—variations due to the airplane rising or settling in updrafts and downdrafts. In nine cases out of ten the accuracy of an aerial survey of such a small area made in a country as flat as the site of Chan-Chan would be sufficient without ground control.

⁷ Holstein, Otto, Chan-Chan: Capital of the Great Chimú, *Geogr. Rev.*, vol. 17, pp. 36–61, 1927.

The second of the surveys of archeological sites which our original plans called for was that of the ruins of Pachacamac, a few minutes' ride from Lima by automobile. Because they are near Lima these ruins are perhaps better known to tourists than any others in the coastal region of Peru. They are the remains of the pre-Inca temple of the Creator-God Pachacamac and the Inca temple of the Sun and the two villages built in connection with them, one of which was used by the permanent residents of the place and the other by pilgrims who are believed to have assembled at this shrine from all parts of the empire.

Flying at an altitude of 10,000 feet we mapped the ruins in a few minutes. Then, going in by automobiles, we made numerous still and motion pictures from the ground.

WORK IN THE CUZCO REGION

While we were making preliminary reconnaissance of the Colca Valley, word came that a landing field had been prepared for us at Cuzco. We decided that the work there had best be undertaken at once before the rainy season set in in the sierra.

On the flight to Cuzco we had our only serious mishap. We took off from Arequipa on May 21. En route the two planes became separated. I landed my ship, the *Lima*, at the Cuzco field located at Anta, a few miles from the city, on schedule; but the photographic ship, the *Washington*, did not show up on time, and a 3-hour reconnaissance flight back to the point where we separated failed to locate her. At midnight, however, word came through from the Andahuaylas telegraph post that the missing ship had been landed on the Huancabamba pampa about 90 miles west of Cuzco, and that, although the crew was unhurt, a wing tip had been damaged.

The following morning we flew the *Lima* from Cuzco to Andahuaylas, taking extra gas and repair materials. After an enforced night on the pampa with a temperature but a few degrees above zero we finally got both planes back to the Anta field. The damaged wing was changed to the *Lima* so that the photographic ship might continue its work with two good wings. Then we attempted to take off the *Lima* for a return flight to our home base where the wing could be rebuilt. Unfortunately the field proved too small for the crippled ship, which was so badly damaged at the take-off that we found it inadvisable to attempt to repair it in Peru.

Our work went on with the *Washington*, now forced to do all the flying. Photographs were made from the air of various archeological sites in the Cuzco region, among them Machu Picchu. These ruins in the Urubamba Valley, "two days' hard journey" on the ground or 45 minutes by air from Cuzco, have been made known to the world

by the labors of Dr. Hiram Bingham. The site is magnificent—above “a stupendous canyon whose rim is more than a mile above the river * * * whose precipices are frequently a thousand feet sheer.”⁸ An incomparable view of the Inca citadel is obtained from the air (pl. 7, fig. 2, and pl. 8, fig. 1).

Another day was spent in photographing Fort Sacsahuaman on the heights above Cuzco, but perhaps the most interesting of our aerial photographs in this region are those of the group of amphitheaters that we came upon in the Maras Pampa about 15 miles northwest of Cuzco (pl. 9, fig. 1). The priests in a church in Cuzco knew of their existence and said they had been used by the Incas for religious presentations during their fiestas. We have, however, not been able to find any mention of them in the literature on the region.

SURVEY OF THE TALARA OIL FIELDS

Our aerial survey of the holdings of the International Petroleum Co. at Talara, northern Peru, was made in February. It seemed to us that the flat, desert country of the Talara fields would be easy to map from the air. Certainly little correction would be necessary in assembling a mosaic from the photographs. Several problems cropped up, however, when the work began: How best to cover the area with ground control; how best to give some relief to the mosaic, to make depressions look like depressions, and oil rigs stand out as other than mere dots on the sand. Clouds also hindered us, since to cover the extensive area economically we had to fly at 15,000 feet, and even on the arid Peruvian coast there are few really cloudless days.

For ground control, in addition to white lime markers at all our triangulation points, we made use of a system developed by Johnson several years ago in which a network of oblique sheets is used to tie in various landmarks so that in making the mosaic for the vertical photographs each point can be definitely aligned. By flying late in the afternoon and for short periods only we utilized the shadows cast by the oil rigs and thus obtained a remarkably realistic picture of the fields.

The Talara engineers, because of previous experience with a careless job of aerial mapping, were frankly skeptical of the accuracy of our work. On checking the first test layouts of the points against their own maps, one section was declared to be inaccurate. A transit crew was put at work to check that particular area, and our hastily assembled map was proved accurate within a few inches.

⁸ Bingham, Hiram, *Manchu Picchu: A citadel of the Incas*, New Haven, p. 39, 1930.

FLIGHT TO HUANCAYO

We had hoped to be able to get into the lowlands beyond the Andes to make a test of aerial survey methods in heavily forested country; but the delays incident to political disturbances following the overthrow of the Leguia government prevented us from so doing. We did, however, make two trips to Huancayo in the upper Jauja Valley—one by rail to get the lay of the land and one by air immediately after the completion of the work at Pachacamac. On our trip to Huancayo by rail we were fortunate enough to locate a good landing field—a strip of road, fairly smooth and sufficiently long to assure safety in landing a ship at 11,000 feet altitude. It was near the Carnegie Terrestrial Magnetism Observatory, where we were also assured by Mr. Ledig, chief of the observatory, of comfortable quarters and the use of a dark room.

Heavy clouds rendered futile the first three attempts to get through to Huancayo by air. On the fourth attempt, however, on April 21, we were successful. It was our first experience in high altitude landing; later we were to make landings at still higher altitudes, but as a first attempt Huancayo will always be remembered. In landing at such heights the speed of the plane is nearly doubled. That is, instead of the wheels touching the ground at 40 or 50 miles an hour they touch at a speed of nearly 100. In the thin air one has to be careful with the controls. The plane will stall with no warning, and sharp turns are dangerous unless the speed is kept well above the minimum.

On account of bad weather conditions we were delayed at Huancayo for eight days. The wait for good weather was well worth while, however. The oblique photographs of the glaciers of that region stand out as the best of our entire photographic collection. It would be impossible to obtain such pictures from the ground.

WORK IN THE AREQUIPA REGION

For the work in the south we were able to use the Akeley motion-picture camera which we had hitherto not been permitted to operate; and Mr. W. O. Runcie, an expert motion-picture man of long experience in Peru, was engaged to help with the photography. On May 4 both ships lifted their heavy loads from Faucetts Field at Lima and 5 hours later landed safely at Arequipa, 7,500 feet above sea level. For the next week we flew steadily, most of the time with the aid of oxygen. Motion pictures and stills were made of El Misti, Ubinas, the Nudo de Ampato, and the high snow caps of Coropuna. Staying aloft for periods of 4 and 5 hours, the planes climbed as high as 24,000 feet, circled over, around, and actually inside of the craters of El Misti (pl. 10, fig. 2) and Ubinas, and landed

on the high pampa, so-called, back of the coast range between Arequipa and Mollendo for a brief examination of the famous La Joya crescentic sand dunes (pl. 8, fig. 2)—dunes that move an average of 60 feet a year and cover the pampas as far south as Tacna.

We also made a preliminary examination from the air of the Colca Valley, some 70 miles north of Arequipa, where 14 "lost" villages nestle on the floor of a steep gorge. Apparently they had long since been all but forgotten until Johnson photographed them on a flight made in 1929 when he was chief photographer of the Peruvian Naval Air Force.

In fact, a desire to revisit and study this valley was our first purpose in organizing the expedition. After our return from Cuzco a land party spent six weeks in the valley, a landing field was constructed, and the whole upper valley was surveyed from the air. The work in the Colca Valley with that in the near-by Andagua Valley, where some 40 small volcanoes, apparently hitherto unknown, were located and photographed, will be related in another article in the *Geographical Review*.

STATIC TESTS

A brief account of our difficulties with static may be of use to others doing photographic work under similar conditions. We found on returning to our Lima laboratory after our work in the north that a good many of the photographs taken at high altitudes were spoiled by static. Streaks and lines crossed and recrossed many of the negatives so as to make them valueless. This is an unsolved problem of aerial photography. Static electricity is obviously the cause, but the exact explanation of its presence and a remedy for its effect are still being sought by photographic experts. It occurs most frequently at high altitudes in rarefied air where static conditions reach a maximum. The static reaches the inside of the aerial camera or is generated there—as by the rapid unrolling of the films—and the electrical sparks and flashes leave their image on the negative.

Experiments in eliminating this phenomenon have been made in the United States, in Canada, and in Europe, not only in commercial organizations but also by Government research laboratories. Progress in this experimentation is greatly retarded by the fact that static conditions can not be accurately reproduced in the laboratory but must be encountered in the air. On some flights roll after roll of aerial film may be exposed with no trace of static. Then on the very next flight dozens of photographs will show its effect.

Although we failed to eliminate the static, we did learn enough about the conditions under which it was most prevalent to cut down materially the number of wasted exposures. Equipped with oxygen

for pilot and photographer we made test flights at altitudes up to 24,000 feet above the sea. In the Fairchild aerial camera, Johnson installed insulating devices, grounding connections, moisture pads, and a dozen or more similar gadgets until the interior of the camera would hold no more.

From those experiments we came to certain conclusions that seemed to be quite definitely established. We got no static effects in photographs made at altitudes up to 14,000 feet provided that the exposures were made on the way up and not on the descent. For some unknown reason there was very little static in vertical photographs, although the reason may be because in the vertical photography the camera was mounted in the ship and not exposed to the outside air as directly as when it was held by hand out of the window in the making of obliques. Whether the sky was clear or overcast seemed to make little difference. Rewinding the film as slowly as possible helped to a slight degree. And, finally, even when the entire roll of 110 photographs was exposed at extreme altitudes the first 50 exposures were generally free from static. The last two experiments are to us the most significant. It seems logical to conclude from them that the speed with which the film is unrolled from the spool to some extent regulates the generation of static; for, as the end of the roll is reached the spool turns faster and faster as the film is pulled away from a core of steadily decreasing circumference. It is our belief that if the film were cut to 50 exposures and rolled on a thicker spool, the occurrence of static would be greatly reduced.

All our lower shots were made on the way up not only as a result of these experiments but also because we found that in coming down from high altitudes the lens of the camera became so coated with moisture that it was impossible to get clear exposures, as no amount of wiping would clear it.

SUMMARY

The Shippee-Johnson Peruvian Expedition, with Lieut. George R. Johnson and myself as coleaders, Irving Hay as pilot, Valentine Van Keuren as civil engineer, and Max Distel as mechanic, was organized to carry out a number of projects of aerial photography and surveying conceived by Johnson during his service with the Peruvian Naval Air Service.

The work of the expedition except for that done among the people of the Colca Valley and based on a questionnaire prepared at the American Geographical Society was almost exclusively photographic. Our equipment was two Bellanca cabin monoplanes, one of which was especially equipped for photographic work of all kinds, and a full complement of aerial cameras and motion-picture machines of the

latest type. Our records are not in written words but in the photographs we have brought back.

The *Washington* was in the air 351 hours, the *Lima* 103½ hours; 40 hours were flown above 17,000 feet with the use of oxygen. The highest altitude attained, just east of Lima, May 1, was 24,700 feet; the temperature at this altitude was 4° F. (60° F. at 8,000 feet).

Complete aerial surveys were made at Talara at an altitude of 15,000 feet; of Chan-Chan at 8,000 and 4,000 feet; of Pachacamac at 2,000 and 10,000 feet; of the Colca Valley at 21,000 feet; and of the Andagua Valley at 20,000 feet. The oblique and vertical aerial photographs totaled 3,000; ground photographs, 1,000; motion pictures, 25,000 feet of standard 35 millimeters, 5,000 feet of 16 millimeters.



1. AN AERIAL PHOTOGRAPH OF THE WEST END OF THE GREAT WALL WITH THE OCEAN IN THE BACKGROUND

There is a great confusion of walls throughout the delta of the Santa River. The photograph shows several in addition to the Great Wall itself, one of which parallels it for a considerable distance and then turns sharply to join it. At the seaward end of the more clearly defined sections of these two parallel walls can be seen the faint outlines of the ruined village mentioned in the text. The road at the right of the photograph is maintained by the Peruvian Government in connection with a small salt-evaporating works located a few miles inland.



2. A SECTION OF THE WALL A SHORT DISTANCE UP THE VALLEY FROM FIGURE 1 (ABOVE)

Here a secondary wall branches off from the main wall. On the hill in the foreground is one of the terrace fortresses of which many examples are to be found on the coastal hills that border the Santa Delta. The two roads—one in the immediate foreground and the other between the wall and the fortified hill—appear well traveled, but it should be remembered that on the rainless Peruvian coast the tracks of wheeled vehicles may remain clearly visible for years.



1. A SECTION OF THE GREAT WALL CUTTING ACROSS THE DRY BED OF A TRIBUTARY OF THE SANTA RIVER A SHORT DISTANCE FROM THE COAST



2. THE GREAT WALL HERE CROSSES AND RECROSSES THE DRY BED OF A TRIBUTARY OF THE SANTA RIVER



1. A SECTION OF THE GREAT WALL BUILT ON THE CREST OF ONE OF THE LONG SPURS OF THE ANDES THAT BORDER THE SANTA VALLEY ON THE NORTH

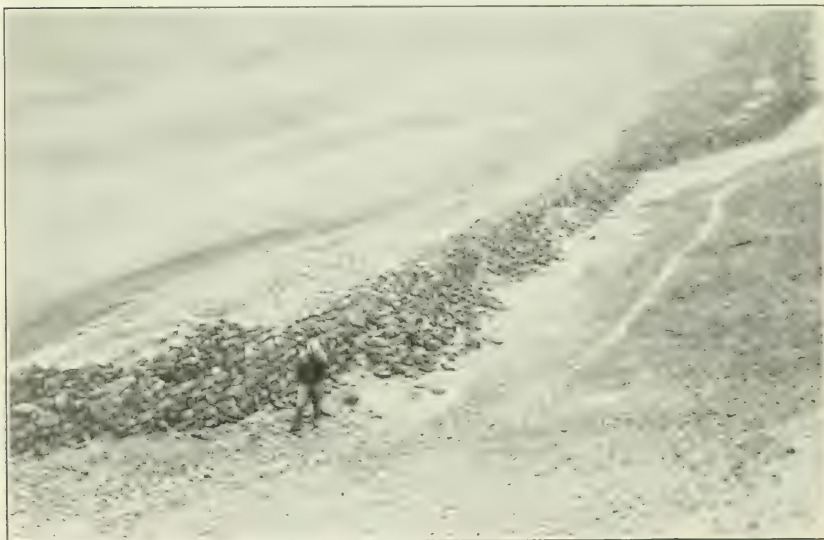


2. ONE OF THE SQUARE ADOBE FORTRESSES THAT GUARD THE WALL ON THE SOUTH SIDE OF THE SANTA RIVER



1. THIS PHOTOGRAPH HAS CAUGHT TWO OF THE HILLTOP FORTRESSES THAT GUARD THE SOUTH BANK OF THE SANTA RIVER

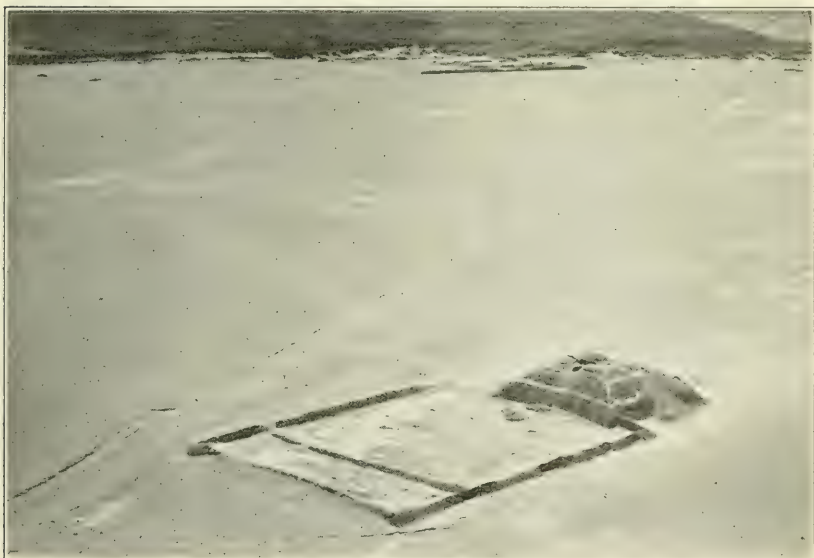
Both are of the adobe structure characteristic of most of the forts on both sides of the river.



2. A SECTION OF THE WALL NEAR ITS WESTERN END WHERE IT CROSSES THE DELTA OF THE SANTA RIVER



1. A SECTION OF THE WALL NEAR ITS WESTERN END SHOWING THE CHARACTER OF THE CONSTRUCTION



2. RUINS OF A TEMPLE IN THE CHICAMA VALLEY WITH A SECTION OF THE WALLED ROAD SAID TO HAVE BEEN BUILT ALONG THE COAST BY THE INCAS AS A PART OF THEIR SYSTEM OF HIGHWAY CONNECTIONS BETWEEN CUZCO AND QUITO



1. A SECTION OF ONE OF THE VERTICAL PHOTOGRAPHS MADE IN THE AERIAL SURVEY OF CHAN-CHAN

The scale of the photograph is about 1:15,000.



2. VIEW FROM THE NORTH OF THE RUINS OF PACHACAMAC IN THE LURIN VALLEY

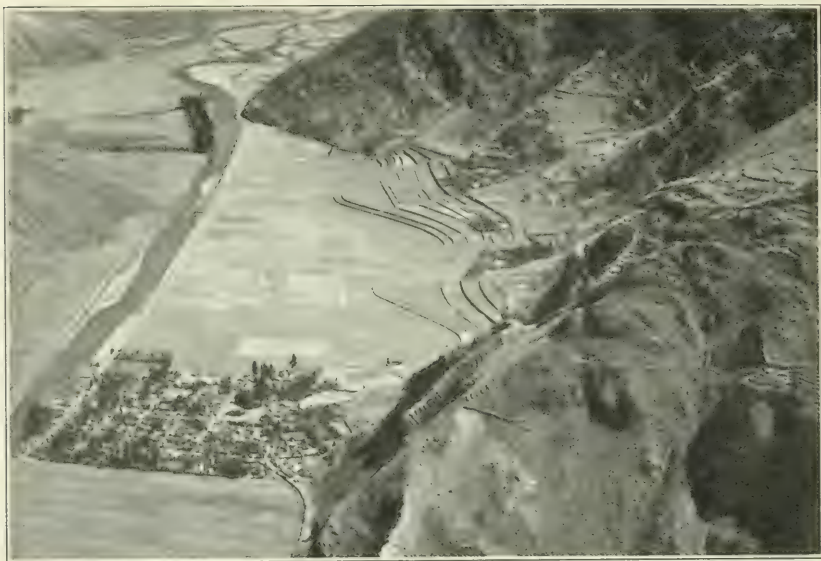
The large block of ruins near the top of the picture is the Sun Temple built by the Incas. Immediately below are the ruins of the much older temple of Pachacamac the chief deity of the region before the Inca conquest. In the foreground are the remains of the villages established in connection with the shrine. Temples and town stand close to the sea on and around a group of low hills above the irrigable level of the valley. The braided course of the river that waters the valley is seen at the left.



1. AN AERIAL VIEW OF THE SITE OF THE RUINS OF MACHU PICCHU ON THE TOP OF A FOREST-COVERED HILL RISING BY SHEER ASCENT NEARLY 4,000 FEET ABOVE A GORGE OF THE URUBAMBA RIVER TO 10,300 FEET ABOVE THE SEA



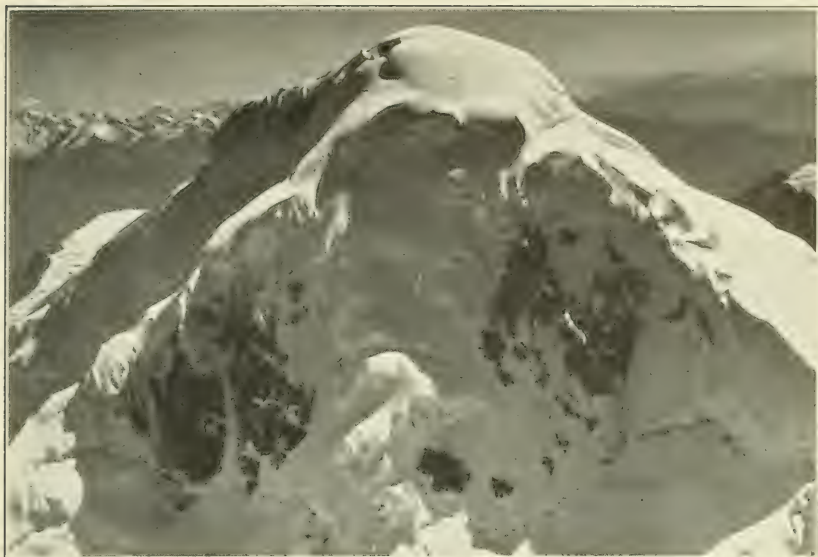
2. A GROUP OF AMPHITHEATERS ON THE MARAS PAMPA ABOUT 15 MILES NORTHWEST OF CUZCO THAT SEEM TO HAVE ESCAPED THE NOTICE OF ARCHEOLOGICAL EXPLORERS OF THE REGION



1. A SECTION OF THE URUBAMBA VALLEY NEAR CUZCO WITH THE REMARKABLY WELL-PRESERVED TERRACES AND FORMAL GARDENS IN FRONT OF THE RUINS OF WHAT IS BELIEVED TO HAVE BEEN THE PALACE OF AN INCA NOBLE
The river is still confined to its bed by stone dikes built before the conquest.

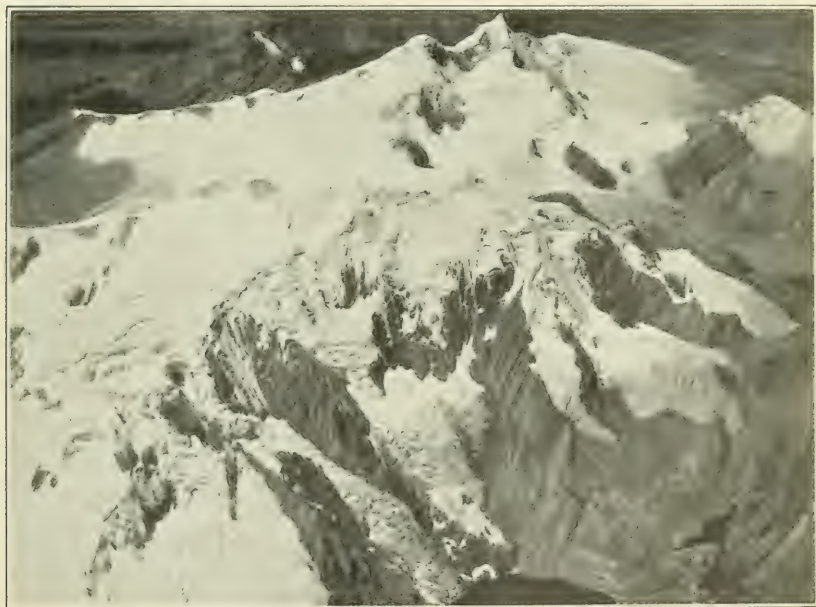


2. A VIEW OF THE CRESCENTIC SAND DUNES THAT DOT THE HIGH DESERT PAMPAS ON THE AIR ROUTE BETWEEN MOLLENDINO AND AREQUIPA
An idea of their size may be had by comparing the one in the foreground with the Bellanca cabin monoplane moored within the inner curve.



1. CERRO VERONICA, A SNOW-CAPPED PEAK 19,342 FEET HIGH, THAT RISES ABOVE THE GORGE OF THE URUBAMBA RIVER ABOUT 30 MILES NORTHWEST OF CUZCO

One of the old Inca routes from Cuzco to the lower Urubamba Valley was by way of a high pass immediately north of this peak.



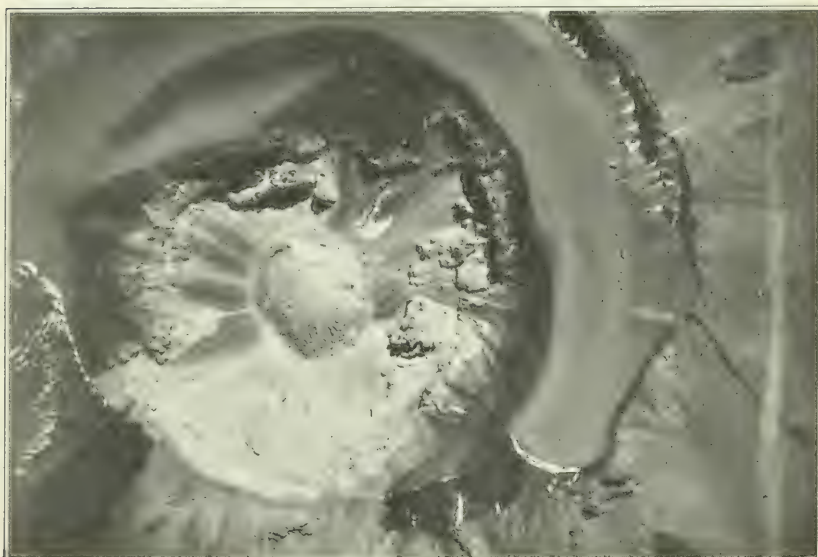
2. CERRO LASUNTAY NEAR HUANCAYO

The snow fields and glaciers of this section are among the largest in the Peruvian landscape. Only from the air could such detailed and comprehensive photographs be obtained.



1. UBINAS VOLCANO (17,380 FEET), A LITTLE-KNOWN CONE ABOUT 35 MILES EAST OF EL MISTI

The diameter of its crater is nearly three times that of El Misti.



2. LOOKING DIRECTLY DOWN INTO THE CRATER OF EL MISTI (19,262 FEET) FROM AN ELEVATION OF 21,000 FEET

The plane was flown down below the rims of both El Misti and Ubinas.

STATUS OF WOMAN IN IROQUOIS POLITY BEFORE 1784

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There are several cogent reasons why this study should close with the colonial period of the British Colonies in North America. The final results of the War of the American Revolution, affecting the affairs of the League of the Iroquois, were the crushing disruption of its vital institutions and the ruthless sundering of the unity of its component peoples into hostile parts which later found precarious dwelling-places in various sections of Canada and in several of the United States; thus the integrity of the League of the Iroquois was irreparably dissevered and dissipated, its fundamental organic institutions ceased to function normally, and so the entire confederate structure of the once famous League of the Iroquois swiftly fell into ruins.

The status and plenary power of the Iroquois woman shared in the common ruin of the vital institutions of her people, and they are in their original integrity forgotten to-day, and lost beyond recovery by her.

Five Iroquoian tribes—the Mohawk, the Seneca, the Onondaga, the Oneida, and the Cayuga—dwelling in the central and eastern parts of what is to-day the State of New York, organized during the heyday of the Stone Age in North America, under the wise guidance of the prophet-statesman Deganawida, a league or confederation of peoples with a carefully designed constitution embodying the principles of health, peace, justice, righteousness, order, and force (or power). In 1722 the Tuscarora were incorporated as a sixth member of this league.

These six tribes spoke dialects of the important Iroquoian stock of languages which is one of the 40 native linguistic stocks of language spoken north of Mexico.

To-day, in consequence of the disintegrating causes mentioned above, every one of these six tribes is divided into two or more independent parts which occupy residences situated distantly one from another; so that none of the six tribes mentioned above exists to-day except in their discrete parts, and none of these parts of tribes is

organized or ruled in accordance with the great principles of the now defunct League of the Iroquois; and so, it may be added, the use of the phrase, the Six Nations of the Iroquois, as being representative of the ancient institutions of the league, is but the droning of a humbug.

It is not the purpose here to define the earlier and characteristic Iroquois woman in terms of the Iroquois woman of the modern reservation system, because the two persons culturally have nothing in common.

Correctly to appraise and appreciate the true status and plenary power or authority of woman in the Iroquois State it is needful to enumerate and to define the several organic units of the league institution, in which her voice and her will through institutional means were made dominant and directive, and thus to understand their relation to the institution of the league as a totality. Only in this manner may the basic character of her rights, plenary power, and essential duties and obligations be fully apprehended.

The institutional organic units constituting the structure of the League of the Iroquois are, beginning with the simplest: First, the ohwachira; second, the sisterhood of ohwachira constituting the clan; third, the clan; fourth, the two sisterhoods of clans in each tribe, the one constituting the father side, and the other constituting the mother side of the tribe; fifth, the union of these two sisterhoods of clans constituting the tribe; sixth, the tribe; seventh, the two sisterhoods of tribes, the one constituting the father side and the other constituting the mother side of the league; eighth, the union of these two sisterhoods of tribes constituting the League of the Iroquois.

An ohwachira was an organized body of persons tracing descent of blood from a common mother, the members being bound together by the ties of common blood, the strongest bonds known to primitive men, and so forming an exogamic incest group by a rigid inhibition of sexual relations among its members formerly under the penalty of death to the guilty couple; the ohwachira, however, did on occasion exercise the right of adopting a person or persons of alien blood, the blood tie being then a fiction of the law of adoption.

The ohwachira was not composed of lesser or simpler civil or political units. But, characteristically, persons were its constitutive units. They were strictly and rigidly organized by their relative positions in the line of descent and by their interrelations established by their relative ages. The performance of obligations and the discharge of duties were implicit in these several positions and so regarded as obligatory.

The said common mother and her daughters obtained husbands from alien or rather unrelated incest groups or ohwachira; but the

children of these daughters belonged to the blood stream of the mother *propositus*.

It has been said that these ohwachira composed clans; ohwachira which possessed chiefship titles received eponyms or group names; but the clans received distinctive faunal names, and so the ohwachira bore a named allied to that of the clan under which it was grouped. Clans bore the names of various animals and birds of the habitat of the tribe to which the clan belonged. So we find the Wolf Clan, the Bear Clan, the Turtle Clan, the Deer Clan, and so on.

It has been said that the ohwachira was highly organized; its members were regimented first by the device of terms of relationship which fixed the status or standing of every member of the ohwachira or uterine incest kinship group. Eldership in this discipline was most important.

The first and highest term is that of mother, which has a much broader and deeper meaning here than it has among white people; it is applied not only to the actual mother but to all her sisters and to all women of her generation in the collateral lines of descent, who among white people would be called cousins; the second term is that of mother's brother, or uncle, which is applied not only to her actual brothers but to all collateral males of her generation to whom white people would apply the name cousin.

Here a word of explanation is needful. The native Iroquois words, sister and brother, as terms of blood kinship have no exact equivalent term in English. These terms in Iroquois terminology denote elder sister and younger sister, elder brother and younger brother. These age distinctions are fundamental and fix the duties and obligations of these members of the ohwachira one to another.

The persons within the ohwachira were largely regimented or classified, if one may so speak, by means of these relationships, which defined implicitly right, duty, or obligation, and these several relationships had well-defined names, so that the right and the duty and the obligation of each person did not have to be obtrusively recalled.

The names of these relationships were the following, namely: Great grandmother, grandmother, mother, uncle (i. e., mother's brother), elder sister, elder brother, younger sister, younger brother, daughter, son, granddaughter, and grandson, niece, and nephew, the last two being used exclusively by the mother's brother.

Questions of honor, of respect, of right, of obligation, and of duty depended upon these relative age distinctions among the members of the ohwachira (or blood-kinship group). It must be remembered that the English rendering of a majority of these native kinship terms can not be considered satisfactory, and need not be pressed.

What is meant here concerning the internal government of the ohwachira may be understood better by several examples than by extended technical verbal descriptions of the entire system.

This important fact shows that primordially the "mother's brother," or approximate "uncle," shared measurably with his sister in her rights and obligations of eldership; and it also explains why the "father's brother," or approximate "uncle," was excluded from the native category of "uncle" and placed in that of a "father" who was an alien in blood descent to the offspring of his brother.

Again, the native kinship expressions, *kteĩ'*ǎ' and *akteĩ'*ǎ', and *hi'gẽn'*ǎ' and *khe'gẽn'*ǎ' (Onondaga dialectic forms), are of equal interest here. The first two are only approximately rendered into English by the phrases, "my elder brother" and "my elder sister," respectively, and the second two expressions by "my younger brother" and "my younger sister," respectively.

It is very plain that the first two cognate forms have nothing in common with the last two with the exception of the prefixed pronouns, namely, *k-*, *ak-*, and *hi-*, and *khe-*, which have only nominative values.

The notional word stem in the first two expressions is *-teĩ'*ǎ', and in the last two, *-gẽn'*ǎ'. These two word stems are clearly radically unrelated, showing that the English renderings largely miss the original meanings of them. But, of course, they correctly allocate the persons designated by them in the general scheme of eldership. The native terms are so ancient that their concrete significations are no longer manifest. But, if a conjecture may be permitted here, it may be said that there appears little doubt that the word stem, *-teĩ'*ǎ', primordially signified "the friend, the protector, or the defender."

Primarily, the verbal stem underlying the native kinship term, denoting "mother," is with little doubt identical with the native kinship term, denoting "mother's brother," usually rendered into English by the noun "uncle," a term which has a signification, however, too comprehensive to translate accurately the native term which strictly excludes the "father's brother" from the category of "uncle."

The collective action of the ohwachira was secured by obtaining the suffrages of the mothers and adult girls in it; but the male members, the warriors of it, might be consulted if considered advisable.

The ohwachira, which in their own right possessed official titles of hereditary chiefships, and lesser officials, filled these offices by nomination by the suffrages of the mothers and adult girls in them. The federal chief who represented the ohwachira in the tribal council and also in the federal council, and the chief warriors as well, were chosen in this manner, usually with the advice of the warriors of

the ohwachira. The woman trustee chief, the highest official known to Iroquois polity, was also nominated and confirmed in this manner. She was the executive officer of the ohwachira and was chosen because of exceptional ability and purity of character; she had a seat in the federal council in addition to her position as a trustee of her ohwachira, and so had a somewhat higher standing and authority than had the male federal chief.

Whatever power and authority were exercised by the woman trustee chieftain were delegated to her by the mothers—the womanhood of the ohwachira to which she belonged—with her nomination and formal installation into office. Did she act collectively or jointly with the woman trustee chieftains of sister ohwachira of the clan, she did so only with the advice and consent of the mothers of her own ohwachirt, she did not possess, and so did not exercise, arbitrary or absolute power.

Jointly in conference the woman trustee chieftains of the sister ohwachira of a clan exercised upon occasion the exclusive right to adopt other ohwachira of alien blood into the clan.

And the council of the woman trustee chieftains of a sisterhood of clans exercised, when such action was properly proposed to it, the exclusive right of adopting an entire clan as a member of such clan sisterhood.

The woman trustee chieftains of the two complementary sisterhoods of clans of a tribe, in session assembled, on proper motion and recommendation, could exercise the exclusive right of adopting another tribe as a sister people. Naturally, in such adoptions the warriors and the council of male federal chieftains were consulted upon the advisability of such action, because very often the requests for such action came from the warriors and the male federal council.

Among the Iroquois, woman was thus supreme in many of the fundamental activities of the community to which she belonged: (a) Descent of blood, which gave citizenship in her ohwachira, and through it to the clan and to the tribe, was traced through her; (b) the official titles, distinguished by unchanging proper names, of the several chieftainships of her own ohwachira and so of the tribe belonged exclusively to her; (c) the lodge or rather her apartment in the ancient long-lodge and all its furnishings and equipment belonged to her; (d) her offspring belonged to her; (e) the right of the use and occupancy of the lands shared by her ohwachira with the clan, as the source of food, life, and shelter, belonged to her; arising from these several vested rights, the woman exercised the sovereign prerogative of selecting from her brothers and sons the candidates for the chieftainships of her ohwachira and clan; and she also exercised the concurrent prerogative of initiating the pro-

cedure for the deposition of these officers for cause; being the source of the life in her ohwachira, and through it of that of the tribe, she exercised the exclusive prerogative of adopting aliens into her ohwachira, and no man had the right to exercise this prerogative; she exercised on occasion the authority of forbidding her brothers and her sons from going on the warpath; not infrequently the male federal chieftains, to avoid a rupture with a foreign people, took advantage of this prerogative of the women, asking them to disband the warriors when they had become unruly and disregarded the wish of the male federal council.

The mothers, the adult women of the ohwachira, because they were the natural source of life in it, exercised the right of granting life or of decreeing death to alien prisoners who might become their share of the spoils of war for the replacement of some of their own kindred who may have been killed; the woman might demand from her husband's clansmen, or from those of her daughters, a captive or a scalp to replace a loss in her ohwachira.

The women of the several ohwachira elected trustee chieftainesses who were the executive officers of the women whom they represented; these female officials provided by public levy or contributions the food required at festivals, ceremonials, and at general assemblies of the public, or for public charity; they kept a close watch on the policies and the course of affairs as affecting the welfare of the tribe as shaped by the male federal council; they guarded scrupulously the interests of the public treasury, with power to maintain its resources, consisting in late times of strings and belts of wampum, quill and feather work, furs, corn, meal, fresh and dried or smoked meats, and of other things, which might serve for defraying and meeting public expenses and obligations, and to have a voice in the disposal of what the treasury might contain. Indeed, the woman owned not only the lands and the village sites but also the burial grounds of the clan in which her sons and brothers, her daughters and sisters, were buried.

The women of the ohwachira sought husbands among the men of ohwachira belonging to clans other than that to which their own ohwachira belonged. As a general statement of fact, the ohwachira owed certain important obligations and duties to the ohwachira in which their sons and brothers had obtained wives and had produced offspring. In the event of the death of such a child, it was the solemn duty of the ohwachira of the child's father to assume at once the tasks made necessary by the event; to care for and prepare the corpse for burial, to dig the grave, to prepare the bark case for the corpse, to provide the food needed for the customary wake or wakes for the dead, to supply a celebrant to make the usual address of

comforting sympathy to the mourning ohwachira, and also at the grave. The mourning ohwachira was by custom relieved of all obligation to work or perform any public business until after the burial and the expiration of the tenth day of the greater mourning.

So, by duties and obligations of affinity like these the several ohwachira were bound together for mutual aid and support, thus forming a congeries of interrelated ohwachira, the essential elements of the Iroquois commonwealth. Thus, the blood stream of descent of the ohwachira was kept flowing unbroken by the mothers in it; and the ohwachira was bound through affinity to alien ohwachira firmly by the bonds of marriage with the men and women of the alien ohwachira.

So strong was the taboo of incest among the members of an ohwachira that, in the event that a child was engendered by an incestuous act, it was declared to have no father's kinsmen, and so could not share in the rights due it from a father's clansmen and clanswomen. Its reproach was that of being an outlaw; for example, it could claim from no kinship group the rites of burial. In earlier times incest was said to be punishable with death for both culprits, since the breaking of the taboo provoked the hostility of the guardian spirits of the ohwachira concerned.

The ohwachira as an organic unit maintained its power and integrity even when incorporated into higher units of organization, thus vindicating and conserving fully the plenary power exercised by the Iroquois woman in the political institutions of her people.

In the league as originally instituted there were just 47 ohwachira which had official representatives in the federal council; that is to say, there were 47 woman federal trustee chieftains and 47 man federal chieftains. At a later date this number was increased to 49 by the incorporation of the last two federal chieftains, named in the modern Seneca roster. This then made a federal council of 98 peers.

The astute founders of the league had made the experiment of entrusting their government to a representative body of men and women chosen by the mothers of the community; they did not entrust it to a hereditary body, nor to a purely democratic body, nor even to a body of religious leaders. The founders of the league adopted this principle and with wise adjustments made it the underlying principle of the league institutions.

The officers of the ohwachira thus chosen by the mothers in it were, in the order of their importance, first, the woman federal trustee chief (named *Akoyānérkō'wā* in Mohawk and *Goyānēgō' nā* in Onondaga), and her aid who was a chief warrior; second, a man federal chief (named *Royā'ne'r*), and his aid or messenger, also a chief warrior; third, two or four women officials who with their warrior

aids had the charge and the direction of the festivals in which they joined with other ohwachira in a common ceremony. Both the woman federal trustee chief and the man federal chief had seats in the federal council of the league. The entire membership of this council thus consisted solely of representatives of the several ohwachira who were chosen by the suffrages of women solely and whose tenure of office was retained by merit during the pleasure of these selfsame women who nominated them.

But, it must be stated here that not every ohwachira had a set of officers of this character; the public business of such an ohwachira was transacted vicariously by the officers of an ohwachira bearing to it the political relationship of sister.

The woman trustee chief had to see that the male and female members of her ohwachira and its officers performed their duties and discharged their obligations as worthy citizens of their community.

It is deemed a matter of historical interest to state here that in most of the available versions (for there are several) of the tradition relating to the birth and life of Deganawida, his mother, *Djigo"sä'sčē*, has unfortunately been displaced by an unhistorical figure, most commonly called "the Peace Queen," "the Mother of Nations," and other equally erroneous epithets, derived from misinformation and too hasty deduction. It seems probable to the writer that this confusion arose from a natural dialectic confusion of native names.

This unhistorical figure is known by the native Seneca name, *Djigo"sä'sčē*; i. e., "the Wild Cat" (literally, "Fat Face"), from the erroneous deduction that she belonged to the Neutral Nation, or to the ancient Erie whom the early French explorers called "the Cat Nation." It is seen that there is a great similarity in the two native names.

The importance and essential character of the ohwachira in the organic structure of the essential units of the League of the Iroquois has so far been briefly reviewed to show how absolute was the woman's control of the functions of the league. The embodiment of the ohwachira in the internal structure of the clan did not then in any essential manner curtail this plenary power of its women.

It is to be remarked that the Iroquois woman was sole master of her person; her husband or lover acquired marriage rights over her person only by her own consent, or the advice and consent of the elder women of her own ohwachira.

This great regard for the person of woman was not limited to the persons of native Iroquois women, but women of alien blood and origin shared with them this respect. For example: In the face of

circumstances adverse to the Iroquois, Gen. James Clinton, commanding the New York division of the Sullivan punitive expedition in 1779, with orders to disperse the hostile Iroquois and to destroy their homes, paid his enemies the high tribute of a brave soldier by writing in April, 1779, to his lieutenant, Colonel Van Schaick, then leading his troops against the Onondaga and their villages, the following terse compliment: "Bad as these savages are, they never violate the chastity of any woman, their prisoner." And he added this significant admonition to his colonel, "It would be well to take measures to prevent a stain upon our army."

The woman trustee chieftainess was selected from the other eligible women of her ohwachira because of her outstanding intelligence, her marked ability, her stability of character, and of the spotless purity of her life; indeed, she was chosen because she embodied in her person the ideal virtues of a perfect, wholesome woman—kind, industrious, intelligent, loyal, and pure in thought and action.

In a portion of the obsolescent story relating to the mother of Deganawida, the founder and organizer of the League of the Iroquois, fortunately recovered during the past year by the writer, there occur certain traditional passages of remarkable value and significance.

In this precious fragment of early Iroquois tradition the mother of Deganawida bears the noteworthy name, *Djigo*"*să'sē*". This name was peculiarly personal to her; it was designed to express a superlative endowment of the noblest attributes characterizing a wholesome womanhood. Its implicit signification is "A face doubly new, pure, and spotless"; i. e., "A face new, pure, and spotless in a superlative degree," exceeding in these attributes the face of a newly born babe. Such was the highly expressive face of the virgin mother of Deganawida as apprehended by the poet annalists of Iroquois tradition. This was, indeed, an apotheosis of womanhood, of motherhood. Such high encomium of wholesome motherhood could have found expression only in a soil and atmosphere enriched by the best in thought and striving of Iroquois womanhood.

In the preceding paragraphs of this study it has been the purpose to show that the spirit of these high encomiums of Iroquois woman by her own people was not spent in flattering lip service, but that it was wisely and firmly embodied in the most vital institutions of the Iroquois commonwealth.

Furthermore, the tradition mentioned above recites the fact that the mother of Deganawida was the daughter of a very poor woman who dwelt apart in indigent circumstances. The birth of this daughter was accompanied by an auspicious omen; she was born with a caul, and in accordance with contemporary beliefs, she was destined

to become a noted and spiritually forceful woman, should she be at once concealed and guarded from the sight and presence of all persons except those of her mother or other trusted person until she attained fully grown womanhood. To make her concealment effective the place of her seclusion was carefully covered with the down of the cat-tail flag or corn husks.

During this seclusion such a person was regarded as under the tutelage of a guardian spirit whose guardianship had begun before birth, and the subject was thought to acquire much abstruse wisdom and spiritual force of character from other tutelaries.

Because of the means employed to make the concealment most effective, such a hidden person was said to be "down guarded," "husk fended," or "down inclosed," and to have acquired a quasi sacred or divine character.

Such a divine person then was the mother of Deganawida. It was, therefore, not at all strange for tradition to assert that such a virgin maiden could receive life directly from the Creator of men, without the physical mediation of the complementary sex. And thus arose the belief that Deganawida had no earthly father, but that his life came to his virgin mother directly from the hands of the Creator. His nativity then was truly a virgin birth.

In her name coming to us from the Stone Age in North America the noun stem, *-go'sa-*, meaning "face," is of course metaphorically used instead of the term denoting the entire person; so substituting the word "person" in the foregoing translations of the name, *Djigo'să'sēē*, its full force and significance becomes clear. The predicative *-sēē*, meaning "new," "fresh from the maker," "pure," "innocent," "infantile," has its force here doubled by the iterative prefix *Djî-* (for *dj-*, "again," "over," and *-ye-*, "one"). So that this characterizing proper name means "The Most New Person," "The Most Youthful Person," "The Most Pure Person," or "The Person the Most Like a New-born Babe."

Hence, at the great installation council in which the federal chieftains received their commissions, both men and women, the mother of Deganawida assisted her great son in this epochal ceremony, and she thenceforth became the type of all future women trustee chieftains. This was another worthy tribute to the worth of Iroquois womanhood.

In the law governing the settlement or adjustment of murders, especially those arising from the blood feud, the legal tender for the killing of a man by another was 20 strings of wampum—10 strings for the dead person and 10 strings for the life of the killer which of course had been forfeited by his unfortunate act. But in the case of the killing of a woman by a man the legal tender was fixed at 30

strings of wampum—20 strings for the woman's life and 10 strings for that of the man; but, if the killer were a woman who had taken the life of another woman, the legal tender in this case was fixed at 40 strings of wampum.

This conclusively shows that the life of a woman was regarded as of double the value of that of a man to the community. This law was enacted for the express purpose of suppressing blood feuds which had been sapping the lives of the brave and had been the source of constant fears.

This great respect for the person of the woman among the Iroquois was thus manifest everywhere. In two of the rituals of the condolence and installation council the following noteworthy language occurs concerning the esteem in which woman was held, namely: "The Creator of our kind has indeed endowed the person of our mother (the woman), with high honor and also with the full measure of mind and reason. Give heed, therefore, to her words of admonition and advice."

A basic rule of the constitution of the League of the Iroquois provided in the event of the extinction of an ohwachira by the death of its women, which possessed chiefship titles, that, for the preservation of this title, the federal council should place it in trust with a sister ohwachira of the same clan to which the moribund ohwachira belonged, during the pleasure of the federal council of the league. This provision was essential since no new federal chiefships were instituted after the death of Deganawida, and it was a requirement of the constitution that all seats of federal chiefs should be kept filled.

The mothers and adult women of an ohwachira possessed the inherent right to hold councils, such as those at which candidates for chieftain and war chiefs were nominated by them. Such a council of women formulated for discussion by the federal council some pressing proposition, in which they might be joined by a sister ohwachira; that is to say, it exercised the right of initiative. In like manner, such a council proposed to the federal council the submission to the suffrages of the people, including children (the mothers exercising the right to cast their votes), any question which might be agitating the minds of the people; that is to say, it exercised the right of referendum. The federal chieftainess exercised the duty of initiating the move for the recall of the federal chief of her ohwachira who had persistently broken his vows of proper official behavior, in accordance with the law governing her position; that is to say, she exercised the right of recall.

One or more ohwachira, as has already been stated, constituted a clan. Where there are more than one ohwachira, they were united

as a sisterhood of ohwachira, and were independent of one another in action. For example: The Mohawk and the Oneida tribes, singularly like some of the Huron tribes in this respect, each had three clans, namely, the Bear Clan, the Wolf Clan, and the Turtle Clan, which were constituted of a sisterhood of ohwachira, respectively; each ohwachira possessed a male chiefship title, a woman trustee chiefship title, war chiefships, and other lesser official titles. The Mohawk Bear Clan, for example, was constituted of the Large Bear Ohwachira, the Weanling Bear Ohwachira, and the Nursing or Cub Bear Ohwachira; these three ohwachira sisterhoods did not have a common regimen—they were each absolute in the management of their internal affairs. These facts again show how woman in the largest practical measure dominated in all the civil and political activities of the Iroquois state.

In becoming an integral part of a clan—a higher unit of organization—the ohwachira necessarily delegated some of its self-government to this higher unit in such wise as to render this coordination of organic units more cohesive and interdependent. The institution of every higher organic unit involved new privileges, duties, and rights, and the individual came under a more complex control and his welfare became more secure through tribunals exercising a greater number of delegated powers in a broader jurisdiction.

The following brief summary of the characteristic rights, privileges, and obligations of the clan may be instructive:

First, the right to a distinctive name, customarily derived from that of some animal, bird, or reptile, characteristic of the habitat, regarded, perhaps, as a guardian genius or tutelary deity; second, representation by one or more chiefs in the tribal and in the federal councils; third, an equitable share in the communal property of the tribe to which it belonged; fourth, the right and the obligation to have the nominations for chieftain and war chief, and woman trustee chieftain, and their aids, confirmed and installed by officers of the tribal council, and since the institution of the League of the Iroquois, by officers of the federal council; fifth, the right to protection by the tribe of which it was a constituent member; sixth, the right to the titles of the chiefships and war chiefships hereditary in its ohwachira; seventh, the right to certain songs, chants, dances, and religious observances; eighth, the right of its men or women, or both together, to meet in council; ninth, the right to the use of certain proper names belonging to the several constituent ohwachira; tenth, the right to adopt aliens through the essential action of its ohwachira; eleventh, the right of its members to the use of a common burial ground; twelfth, the right of the members of its constituent ohwachira, possessing official titles, to nominate candidates for chieftain,

trustee woman chieftain, and chief warrior (some clans have more than one of each class); thirteenth, the right and obligation to share in the religious rites, ceremonies, and public festivals of the tribe and the league. It is thus seen that a large number of the essential attributes of the ohwachira may be predicated of the clan which did not absorb the identity of the ohwachira.

A dispassionate survey of the underlying principles and general laws and regulations of the League of the Iroquois for the purpose of becoming acquainted with the mood and spirit in which they were conceived reveals the startling fact that the hand, the heart, and the mind of woman had a directing and molding influence in their formulation and expression, for in noteworthy fashion they are uniformly humane—even tender, tolerant, beneficent—and prudently designed to secure the well-being of contemporary and future generations; they are not harsh, not truculent, nor defiant of reason.

The watchful anxiety manifested for the peace and welfare of the children of the Commonwealth of the Iroquois clearly shows the insistent expression of mother love as its primary source. This love of children breaks forth full blown in the charge to the newly installed federal chieftain, who is the executive representative of woman in the discipline of government.

In this remarkable charge, the newly installed chieftain is urged, as one of his most important duties, to devote anxious and especial care to securing the well-being of "the children who, running to and fro, sport about him; of the children who, still creeping, propel themselves about him in the dust; of the children whose bodies are still made fast to cradle boards; and lastly, even of those unborn children who, with faces turned this way, are on their way hither below the surface of the earth." So that these little ones "might have peace of mind and body for even one poor day."

In North America the status and the plenary power of the Iroquois woman in the period covered by this study were unmatched achievements of native statecraft. In her keeping were the purity and nobleness of blood, the order of generations in the genealogical tree, and the conservation and perpetuation of the ohwachira or uterine family brood through the pains and cares of motherhood; these were each and all inherent in her person. She indeed possessed and exercised all civil and political power and authority. The country, the land, the fields with their harvests and fruits belonged to her. The order of official succession was founded in her blood; her children belonged to her; she presided at the contracting of marriages affecting her ohwachira; in the crisis of events the decision of the question of war or peace fell to her arbitrament; her plans and wishes molded the policy and inspired the decisions of councils.

Although the male federal chieftains were chosen by her from among her brothers and sons to consider and decide public affairs, they did not act for themselves but only as the representatives and delegates of the woman in those matters which did not seemingly require her presence. Even the names of her children came from her.

In striking contrast with these powers of woman, the Iroquois men were quite apart and restricted to themselves; they perpetuated nothing; their own children were aliens to them. With their passing everything ceased to be—the ohwachira or uterine family brood became extinct. Nothing was passed on by them. If there were only men left constituting the remnant of an ohwachira, in whatever number they might be, or whatever the number of the children they might have, this ohwachira was already extinct.

This was true because the children of these men would belong to the ohwachira of their mothers. The woman alone through her progeny preserved the continuity of the blood of the ohwachira to which she belonged.

With the destruction and subversion of organic kinship institutions of the Iroquois state through direct impact with the white man, the Iroquois woman quickly lost her unmatched pristine status and her plenary social and political power, and so her dispersed descendants to-day are groping among those ruins perchance to find her lost jewels.

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